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THE MINERAL INDUSTRIES OF THE UNITED STATES

COAL PRODUCTS: AN OBJECT LESSON IN RESOURCE ADMINISTRATION

BY

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Curator of Mineral Technology, United States National Museum

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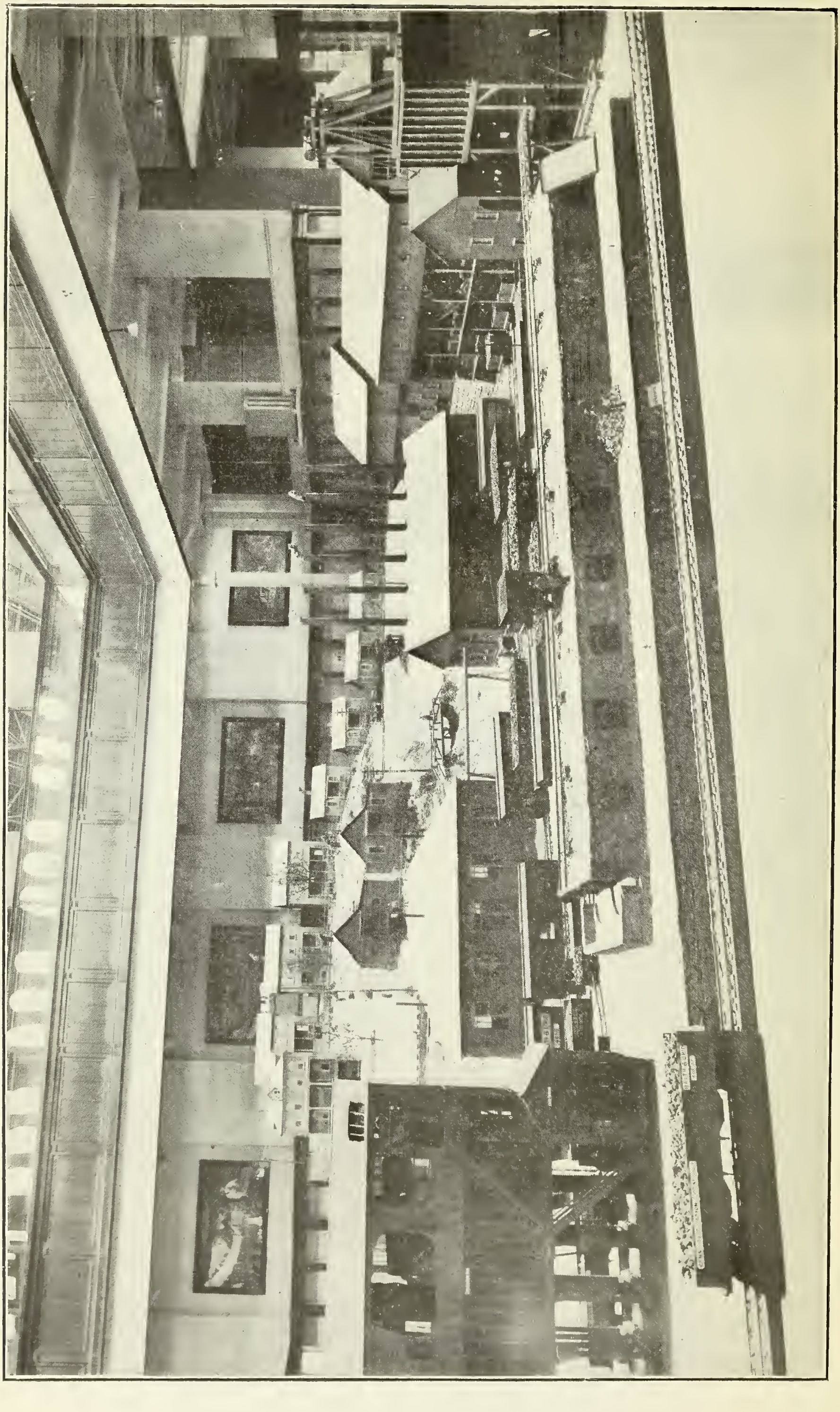

VIEW OF COAL PRODUCTS, EXHIBITION HALL, UNITED STATES NATIONAL MUSEUM.

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COAL PRODUCTS: AN OBJECT LESSON IN RESOURCE ADMINISTRATION.[1]

By Chester G. Gilbert,
Curator of Mineral Technology, United States National Museum.

Civilization's foremost function is the nourishment of human life and manufacture is the expression of man's effort toward providing the broadened means toward this end. The mere vision of smoke and grime and the grinding away of human lives in the purely selfish search for material profit is superficial. The deeper significance of manufacturing industry is that of providing the essentials for multiplying humanity, and to make the most of potentialities toward manufacture is not merely to set up a goal of self-aggrandizement; it is one of the profoundest obligations of a people in behalf of posterity, even in behalf of the world at large to-day. If this is true of industrial enterprise as a whole in its relationship to national responsibilities, it applies with altogether distinctive emphasis to the activities involving a country's coal resources. Mankind is dependent upon coal in the home; but more than that, coal contributes the muscle and sinew for industry whereby practically every other material necessity of life is rendered available to use; and even in addition to being the fuel dependency of the age, it is capable of being made to yield an almost indefinite number of other necessities without sacrifice from the fuel element.

Coal in short is the nucleus around which the material growth of civilization builds. Thus an explanation opens up to the fact that Europe is the center of present-day civilization. Coming into existence there, the civilization of the present era found, when the need developed, ready at hand in the form of adequate coal resources, the means toward the evolution of its destiny. Thus the series of cubes shown on plate 3, sized proportionately to the coal resources of the various continents, is highly suggestive with reference to the future indicated for the maturing aspects of this civilization in its spread toward world inclusiveness. One sees a vast industrial rehabilitation in Asia, while the responsibilities of South America and Africa are indicated as lying essentially in the provision of raw materials, and Europe would presumably become more and more the source for refinement of industrial procedure and the clearing house of world trade.

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[1] Interpretation of the Coal Products Exhibit in the U. S. National Museum.

For additional comparison, a cube showing the relative importance of the coal resources of the United States is given place in the series. Noting the share of the world's supply thus represented, a conception of the industrial potentialities of this country opens up, reaching beyond the grasp of the imagination. Yet entrusted with a great share of what the whole world has to rely upon for material support in the encompassing progress of civilization, the yield from this vast heritage has not been made to respond adequately even to current purely domestic needs. True, it is energizing a vast industrial development, and thus far at least it has met the fuel requirements of the American home; but these are only two of its three functions, and as a matter of fact their ends are attained through the actual normal employment of only about two-thirds of the mass representing coal. The other third embodies a veritable treasure house of products catering to needs of civilized man, and the spectacle of the United States, with its dominating bulk of potentiality, helplessly pleading with European countries to render coal-product assistance despite the overwhelming nature of their own troubles, is fresh in the minds of all. It is not a spectacle to be proud of, but it is one well worth contemplating in the light of an object lesson.

Growing out of the composition inherent in the nature of coal, the subject may be approached to best advantage along the lines of origin. Taking the averages of composition representative of each coal type, it will be found that these are capable of an arrangement wherein the various familiar classes of coal such as lignite and anthracite appear as so many stages in a process of chemical evolution. Such an arrangement is represented in graphic form on plate 1 and points significantly to vegetal accumulations as being the source of coal. The further confirmation of the same, the actual fossil outlines of vegetal remains found in diminishing fullness of preservation from peat upward through the successive stages to anthracite, are conclusive. In fact, the fossil forms of vegetation are sufficient to enable the imagination to supply what is lacking and depict original conditions with reasonable assurance of accuracy. This has been done by Unger, among others, and his restoration is reproduced on plate 2.

It is to be observed to-day that the thickness of the vegetable mold blanket bears a direct relationship to the degree of moistness. This is partly owing to the increased luxuriance of growth under such conditions and partly due to the protective influence the water exercises against the oxidizing attack of the air; and the combined tendency of both together is toward providing an increased rate of accumulation over that of decomposition. Where conditions have been particularly favorable to the maintenance of the relationship just mentioned, peat bogs are the result. Peat accumulations as much as 40 feet in thickness exist, and while there is a vast gap between even a 40-foot peat bog and a 40-foot coal bed when it would require the carbon of a 40-foot thickness of peat to yield a 1-foot thickness of coal, still, as indicated above, a complete chain of connecting links in material fact exists, and the only leeway for divergence in theory lies in modifying the details of condition with a view to accounting best for the enormous lateral extent and thickness of the accumulation.

Entering into this discussion only sufficiently to derive an explanation for the present occurrence of coal as a formation between the more conventional rock types of shale and sandstone, down in the earth's solid crust instead of on the surface, as its origin would suggest, the most satisfactory inference is that of a vast marine swamp area gradually sinking. This does not require any stretch of the imagination, inasmuch as progressive changes of this order characterize the relation between land and sea elevation in general to-day.[1]

With the balancing tendencies of a swamp area slowly settling and of organic accumulations slowly building, a shallow swampy character of inundation might well be protracted indefinitely, allowing for a correspondingly indefinite thickness of peat-like accumulation. With the rate of submergence at length gradually gaining the upper hand, vegetation would slowly be drowned out, and the area absorbed into sea bottom by the encroaching water. Then in the largely land-locked sea area resulting, the relatively calm waters would receive the silt from inflowing streams and let it settle quietly to the bottom, thus allowing for a continuance of the process of accumulation, but causing a change from organic carbonaceous material to that of an inorganic clayey nature. Realizing the relative boundlessness of geologic time, proceedings in this stage in the evolutionary process would be capable of any degree of extension, resulting in the burial of the organic deposit under an indefinite thickness of sediment whose character might change with changing conditions of submergence from essentially clayey to essentially sandy, or essentially calcareous matters, yielding almost any thickness of layers. Ultimately, however, the proceeding enters into another stage in the form of a reversal to a rising instead of a subsiding movement. This in due season means the final reappearance of the area as dry land with the one-time swamp accumulation of organic matter buried deep down in the earth. The pressure of the vast weight of materials above, coupled with the various other geologic agencies needless to recount here, will have compressed and condensed the peaty aggregate to coal and welded the sediments into beds of shale, sandstone, and limestone, as exemplified in plate 5.

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[1] For instance, to the northward of the general vicinity of New York the land of the coast line is subsiding while to the southward the reverse is true. Incidentally it is the advancing water boundary with its encroachment upon the land surface in the one case, and the receding water boundary with its consequent exposure of beach area in the other, which accounts for the rugged New England coast and a flat sandy South Atlantic coast.

With the emergence of the region as dry land, the process of coal evolution enters into its closing stages. Erosion or the gradual wearing down of all land areas provides the reverse aspect of accretion or the building up of sea-bottom areas; and the rate of erosion is commensurate with the abruptness of elevation. It is not to be expected that the dynamic forces behind the upward movement would necessarily produce an even uplift; rather it is to be expected that zones of relative weakness would develop and that the uplift would be uneven. Erosion then would proceed unevenly over the area; and in the course of geologic time might here and there succeed in wearing completely through the overlying rock mantle, even cutting through the coal and far into the underlying rock. The result would be the outcrop of a coal bed, and from that point forward the material history of coal, till then involving time in periods defying any attempt at reference to human standards of measurement, is ready to merge into the history of man.

From the foregoing brief sketch of the history of coal evolution, it will appear by way of introduction to what follows that coal is a development from organic accumulations, effected presumably in vast marine swamp areas, and the various classes of coal represent so many different stages in the transition from vegetal to stony condition of occurrence; that the transition is induced primarily by the physical element of pressure with its accompaniment of heat; and that accordingly the anthracite stage of the evolution does not necessarily imply a formation of greater age, but rather marks a more extreme phase of metamorphism whether from duration or from intensity. The natural tendency from external pressure is toward condensation, and that is precisely the nature of the evolutionary development wrought by the dynamic forces of pressure and heat in coal. Physically it takes the direction of a progressive condensation toward the stony extreme of anthracite; and chemically, as may be observed in the chart, there is a corresponding tendency in the progressive elimination of the lighter, gasifiable, or volatile ingredients. These are the conditions native to the occurrence of coal which furnish the groundwork for the structure of industrial usage.

Within the immediate range of vision of a great share of the public, anthracite offers an even more familiar sight than the bituminous grades of coal; and, as a matter of fact, quite apart from the more intimate nature of its relationship to household economy, it furnishes nearly a fifth of the total for consumption. In the face of this ratio in consumption, the extent of the country's resources in the two directions provides a contrast replete with significance in connection with the domestic fuel situation. From the evolutionary sketch it comes as a natural inference that the occurrences of anthracite are restricted, but the degree of limitation affecting its occurrence is not generally appreciated. A map of the United States showing the areal distribution of the two is reproduced on plate 4, and a graphic expression of the comparison in terms of bulk is included amongst others on plate 3. A glance at these is sufficient for the conclusion that the responsibility imposed on anthracite coal is out of all proportion to the resources at hand.

The present purpose is not concerned in the moral issues involved between anthracite production and consumption. It is enough that there exists the national predicament of a household fuel dependency so restricted as to be open to control by the merest few operators acting in concert. Furthermore, whatever the call for the exercise of a corrective influence over the conduct of the operations, fundamentally the predicament, with all of its unfortunate tendencies, arises as the normal outgrowth from an ever-increasing demand upon resources of an altogether disproportionately limited order. Accordingly the mere heaping of condemnation upon what, despite any incidental shortcomings, constitutes one of the most efficient types of producing organization in American industry is as futile as it is superficial. Substantial relief is to be found only in some form of fundamental revision opening up enlarged domestic fuel availabilities.

Only the unsubstantiated imagination can range beyond the use of coal in one guise or another as a fuel basis, so for direct practical results the country must turn to its vast bituminous coal resources. The prospect opening up directly in the extended use of raw bituminous coal is not a refreshing one, however, for aside from the discomfort it means to the individual user, it brings a vision of disaster impending over the work of civic betterment. Smoke, it is true, merely implies incomplete combustion, or, in other words, the escape of distilling volatile matters before they may be consumed, and insuring complete combustion would in itself obviate the smoke-producing objection to raw bituminous coal; but complete smokeless combustion as a result from the general use of bituminous coal in the home at least may safely be regarded as an unattainable ideal. Smokeless combustion as a generally applicable reality can result only from the general use of a smokeless fuel. With the passing of anthracite, the great natural smokeless fuel, into the realm of life's luxuries, hope must look toward the development of a new smokeless fuel dependency artificially from bituminous coal. The relationship between the two types as brought out in the historical sketch lends plausibility to the idea; in fact, makes it appear logically to be expected, for if nature evolved smokeless anthracite from bituminous coal it is natural that man should seek in the same direction for its artificial equivalent. As a matter of fact he has not needed the inspiration to be found in the example furnished by nature. The evolution of a smokeless carbonized fuel is the first stage in the burning of bituminous coal.

Exposed to the temperature of boiling water, some of the volatile ingredients in the make-up of bituminous coal begin to break loose and escape as gas, and as the temperature increases the process becomes more active, giving rise to flame or smoke. After more or less protracted exposure to red heat all of the volatile ingredients are freed, leaving a solid residue amounting to approximately two-thirds of the original coal weight, which then burns quietly without flame or smoke. Extinguishing the fire as soon as the preliminary distillation stage is past instead of allowing it to continue through the smokeless stage of combustion, the residue will have a chemical composition analogous to that of anthracite and from the chart, on plate 1, the chemical procedure itself will be seen to be similar to that involved in the natural evolution of coal. Physically, however, there is an important difference in the two, the importance of which will be dwelt upon later. In nature's laboratory the agencies of pressure and time duration were expended with a lavishness beyond all hope of human approximation, resulting in the dense stony characteristics of anthracite, whereas in the artificial product the escaping gas in the pasty body of the distilling coal develops cellular structure exactly comparable to the familiar instance of bread making.

This coherent spongy mass representing the nonvolatile residue left over from the distillation of the volatile ingredients in bituminous coal is known as coke. Coke then is the artificial expression for the results attained by nature in the form of anthracite, but with important differences arising from the fact that whereas the latter is the outcome from a geologic vastness of time and pressure operating in conjunction with heat, the former comes as the direct response to heat alone. Around coke centers not only the opportunity for relieving the domestic fuel situation, but every manner of coal-product supply as well, so a special degree of interest attaches to its character and adaptability, the more especially since coke is not altogether unfamiliar as a household commodity and has been to a considerable degree misjudged as to its possibilities of value.

Weight for weight coke offers about twice the bulk of coal, and the result is a corresponding difference in fuel properties, as anyone who has used coke has experienced. Speed or energy of combustion is of course proportionate to the area exposed to the attack of fire, and, conversely, susceptibility to chilling below combustion temperature, or to "going out," varies in like manner. Thus the greater bulk of coke with its aggregate of cell walls means a correspondingly increased surface exposure to attack in burning, and under adequate conditions a correspondingly more intense fire. Thus, too, on the other hand, it means a correspondingly greater liability to become chilled and extinguished if neglected. In short, lightness of substance giving a flighty tendency toward extremes of behavior are the outstanding characteristics of coke as a fuel.

Where an extreme of clean heat is the aim, coke is the best practicable solid fuel obtainable, and hence its adaption as the standard for metallurgical use. But susceptibility to control is one of the first requisites for a satisfactory general-purpose fuel, and accordingly coke has not found favor in that direction. In view of the prejudice existing against it, several facts deserve consideration. In the first place the whole development of coke quality has been in the direction of obtaining the maximum of intensity in combustion under the designation of metallurgical coke, a specialization quite at variance with the requirements of a general use fuel. Again, the use of any particular fuel requires appropriate facilities and understanding, and to condemn coke on the basis of its behavior under the treatment evolved for coal is comparable to judging the merits of anthracite on the basis of its behavior in a wood stove. Finally, the question which is slowly and certainly gaining in pressure, is not that of providing a fuel competitive with anthracite on equal terms, but one capable of practical service in the capacity of a commodity as against anthracite in the growing capacity of a luxury. A tendency away from anthracite is certain to set in, and the only room for choice lies between coke and raw bituminous coal. Relative economies are bound to be an important factor, if not the deciding one, in the choice. Right here the domestic fuel situation in the United States connects up with the coal product one in a manner which renders the two interdependent in their requirements; for if the general purpose use of coke fuel is to be economically practicable, it can be rendered so only through the support of values derived from that other third of bituminous coal mass removed as volatile matters in the course of carbonization, and, conversely, an extensive preparation of coal products necessitates an advantageous coke market. The answer to the whole question is to be found in the value of the distillates derivable. If this latter can be made to overbalance the cost of preparation, the surplus constitutes just so much potentiality for economic advantage in favor of coke for the householder.

The volatile third of bituminous coal as it distills off on heating consists essentially of the familiar household-commodity coal gas, commonly supplied to municipalities. Thus, quantitatively, there are two major products from coal, and as a matter of fact the coal-product industries of to-day are a development from two distinct industrial sources, the one producing coke for metallurgical use, the other providing a municipal gas supply. A large measure of this original distinctness has persisted even to the present day in America, despite the remarkable fact that the only essential difference is that the product in the one case constitutes to a great extent the waste or at least the inefficiency in the other, and the reverse. The fundamental aspects of each separately, followed by the combination of the two into a mutually complementary whole, provides the best approach to the present coal-product industry whereby, as has been indicated, the opportunity for a smokeless fuel supplemental to the waning anthracite resources is to stand or fall.

The relationship which coke bears to coal parallels that of charcoal to wood and the manufacturing procedure has developed along similar lines. If bituminous coal is ignited and allowed to burn with sufficiently limited air supply, the burning will be confined to the escaping volatile portion; and, in turn, the heat of this gaseous combustion will maintain a temperature in the coal mass sufficient to cause complete distillation of the volatile ingredients, yielding coke as the product. The earliest application of this principle to coke manufacture was in the form of open-heap roasting, illustrated in plate 6, but this procedure quickly gave way to a practice of burning within an oven so constructed that the incoming air, instead of passing through the coal bed, meets and mingles with the distilling gas in the dome-shaped upper part of the oven, where combustion is accordingly confined. The inclosed oven with its dome-shaped roof is known as the beehive coke oven. In it the only product saved is coke, the volatile matters providing the fuel for their own distillation. If instead of some form of direct smothered combustion such as that provided in the beehive oven, however, the coal be heated in a sealed inclosure—a retort, in other words—the distillation will proceed as in the open, and the entrapped gases and vapors may be piped off from the retort to suitable receptacles for further treatment. This is the principle upon which municipal gas works supplying coal gas operate. Just as the battery of beehive coke ovens is to-day's expression of the solid fuel line of coal-product development as a distinct issue, municipal gas manufacture, the other distinct issue, finds its typical expression in the arrangement of retorts illustrated under the name of gas bench on plate 8.

Contrasting the operations of the two, the beehive oven is open to the air whereas the bench retort is sealed off from air; the beehive oven is heated by the combustion of its oven gases within the inclosure while the bench retort is heated from an external source commonly derived from its own coke of earlier yield; and lastly the production of first-quality coke is the one and only aim of the beehive operations whereas the bench retort includes the production of first-quality gas along with the incidental saving of a more or less nondescript coke and possible eventualities in all of the other coal distillation products:[1]

In the case of the gas bench, the coke yield is of a quality unsuited to metallurgical use; in the beehive oven on the other hand only a small fraction of the gas generated is necessary under adequate conditions to maintain the temperature necessary to distillation. Accordingly two industries exactly complementary in fundamental character, were obliged to travel their own courses of separate wastefulness side by side for upward of half a century, pending the evolution of a system combining the coke advantages of the beehive oven with the distillate saving of the retort type. The problem offered manifold complications in the form of operative efficiency, and despite the heralding of various attempted solutions, it was not until the decade beginning in 1880 that installations fully adequate to the test of practice were established. Credit for the accomplishment belongs unqualifiedly to German enterprise. Once established, advance was rapid, and the coming of the present century found an extensive coal by-product industry centered in Germany and the beehive oven battery supplanted throughout continental Europe by the so-called by-product coke plant.

The aim in the by-product coke plant is, as its name implies, the generation of a coke in conformance with the standards set by the beehive oven, coupled with the saving of volatile matters effected in connection with the gas retort. In principle the modern procedure is identical with that of the gas bench, the essential difference originating in the practice of employing retorts of many times the capacity of the gas retort with a proportionate rearrangement and elaboration of plant construction throughout. The retort ovens are long narrow rectangular gas heated inclosures, ranged side by side in batteries, to allow for mechanical charging and discharging and similarly the treatment accorded the various by-product recovering steps is marked by a maximum of saving elaboration. The general nature of the procedure will be found illustrated and explained on plate 9.

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[1] The beginning in the history of the two developments may be of interest in passing. Back as far as 1817 the Pittsburgh Chamber of Commerce, noting the rapidity with which the wood supplies available for the preparation of charcoal fuel, the accepted metallurgical fuel at that time, were becoming depleted, commissioned a representative to investigate a rumored usage in England of a product of similar derivation to charcoal only from bituminous coal instead of from wood. The rumor was substantiated and presently the product known as coke began to find favor among American metallurgists. From these beginnings the metallurgical use of coke has grown steadily to the present vast proportions involving an average of over a million tons of coal a week in its preparation. The uses of coal gas began further back in 1792 when William Murdock illuminated his home in Redruth, England, with the distillate from coal in a retort which he devised for the purpose.

Tracing the course of the operations as depicted it will be observed that in addition to coke as the major product, the output includes gas, tar, and ammonia, the latter either as such or in the form of the sulphate. By the introduction of additional installations, omitted in the interests of simplicity, the segregated recoveries may and commonly are extended to include benzol and perhaps one or two other derivatives of lesser import. These, together with a 12 to 15 per cent increase in the coke recovery, constitute the direct results accruing from the modern type of operations as contrasted with the crude procedure represented in the beehive oven. More definitely expressed, the contrast means a saving of around 200 pounds of coke, about 5,000 cubic feet of gas, some 15 gallons of tar, and the ammonia in 20 pounds of ammonium sulphate along with 2 gallons of benzol for every ton of coal coked.

The operations represented in the illustration with the products given comprise the immediate field of by-product carbonization as employed in direct opposition to the beehive type of procedure and to the operations growing out of the gas retort bench. The development of the principle has not stopped here, however, but has been extended to fulfill a far greater, more comprehensive function with reference to human welfare through what is termed the coal-product industry and its consequent coal products or coal-tar derivatives. The diagram prepared by the United States National Museum's valued contributor, Mr. C. G. Atwater, and reproduced herewith through the courtesy of the Barrett Co., of New York, outlines better than words the whole potential significance involved.

The diagram is suggestive in three directions of importance in the present connection. First of all it brings out the relationship of by-product coking to the coal-product industry as a whole; namely, that of being only a preliminary though an indispensable preliminary to the whole. Next it provides a definite basis for a comprehensive imaginative grasp of what the industry in its fullness of development has been made to contribute toward furthering the ends of progress. Finally, it leads to the all-important conception of a single great intricate evolutionary creation, the various specific industrial members of which can function only as they operate in coordination with the rest. These three are the essentials fundamental to an understanding of the coal-product situation as it has come to exist in the United States to-day.

Of the foregoing three considerations, the first named, that of the capacity in which by-product carbonization appears, is a connection too fully evident in the diagram itself to call for further comment. With reference to the second, the importance of the products to society, pages would be involved in any attempt to trace with anything like finality the influence of the various products specifically. The significance involved in the situation as a whole, however, is capable of expression in terms of a simple comparison. On the one side stands the chimney stack with its all too familiar contribution; on the other an elaboration of industry offering instead a veritable storehouse of treasure to the use of society; a storehouse affording essentials in agriculture, pharmacy, photography, textiles, disinfection, explosives, refrigeration, painting, paving, waterproofing, wood preservation, and an ever-widening circle of more specific requirements touching every aspect of human life. The magnitude of the contrast is precisely the measure of coal-product potentiality.

Another and more far-reaching significance attaches to the comparison, a significance in which the fundamental reason for the inadequacy of the country's coal-product developments may be recognized. The one, a direct hand-to-mouth economic procedure, is the attribute of a cruder stage of social evolution; the other, an elaborately involved adaptation, can come only as the outgrowth of refinement. The resources at hand awaiting employment in the past have exceeded in both magnitude and multiplicity the facilities available for their adequate utilization. The consequence has been toward preserving the cruder economic tendencies with expression in the form of dissociated opportunist industrial activities rather than toward the evolution of any true economic organism of coordinated industrial parts. Coal-product manufacture, with its elaboration of complex interrelationships calling for coordination of development along scores of directions at once highly specialized and widely diversified, represents the most advanced order of industrial evolution thus far attained. Amid the crudity characterizing the American economic system in the past such an establishment would have been as incongruous and as incapable of growth as a movement toward internationalism in the environment of the Dark Ages.

The dawning of economic consciousness in the progress of a civilization is marked by evidences of a hoarding instinct. So in the belated evolution of the scheme of industrial life in America the past decade has manifested in the crude conceptions of conservation sporadic evidences of a similar stage with reference to the application of industry to the natural material resources of the country. Crude though these conceptions have been, to ridicule them in the light of existent conditions means failure to recognize in them a step in advance toward a riper consciousness of national responsibilities in that conservation which, looking toward adequacy of employment rather than improvidence on the one hand or static hoarding on the other, seeks consistently to bring about the employment of the various means toward that end as they emerge from the channels of research. Vaguely an awakening consciousness in public opinion is coming to a discerning conception of some such national economics, but as in the conspicuous instance of the nitrogen situation, the response thus far has been spasmodic, uncomprehending, and expressed through media inadequately developed.

With the resources of a country constituting the opportunity opening to its people, it follows that enhancement in the value of a natural resource is bound to represent not merely increased dividends for a favored few, but, in the last analysis, an actual corresponding increment to genuine unrestricted opportunity. In this connection, with coal the country's greatest material heritage, the growth in its potentiality as yet ignored, furnishes a most impressive object lesson in resource administration. Twenty-five years ago the practicable potentiality recognized for the use of bituminous coal was approximately:

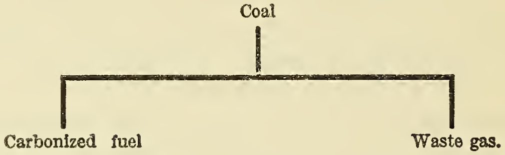

Plate 10 gives the current expression of precisely the same situation. The two speak for themselves, offering a contrast of growth which challenges duplication elsewhere in the whole progress of civilization for a like period of time. Important enough in its specific fact of application to the country's dominant material resource, the full significance of the contrast opens out in proportion as it is seen to apply throughout the whole range of chemically conducted industries, whereby the raw resources of a country are being consumed in the saving or wasting of the multitudinous products essential to the ever-widening requirements of independent national existence.

There is a popular form of misconception which holds the impression that the source of a given commodity is immaterial so long as the needs with reference to that particular article by itself are met advantageously. Fifty years ago such an impression represented a reasonably accurate interpretation of existing conditions, but of recent years a totally different situation has been developing. The change has been brought about through the constantly widening circle of acquaintanceship being made by chemistry amongst the ingredients entering into material compositions, and has manifested itself in the branching out of the opportunities open to industrial procedure. Twenty-five years ago a raw resource commonly lent itself to characterization as a commodity plus impurities; but to-day it offers instead a composite of ingredients, some recoverable to advantage under existing conditions, others not open to profitable recovery, but all possessing definite individual properties, open to employment in meeting the widening needs of civilized man. The term "waste" employed in designating the discards from industrial procedure is more than a name; it is a highly significant characterization. A very large numerical percentage, including even the more important commodities in current use, are of by-way derivation; and the rate at which their numbers increase marks the industrial progress of a people, for therein lie the greatest of all potentialities, not only for practicable resource conservation but for all-round economic efficiency as well.

The results of this broader conception find their expression in the extended application of methods for the recovery of these so-called by-products as soon as the requisite demand is created. In some instances a given by-product is recoverable by itself independently of its associates, but, in the nature of things, it more frequently happens that a whole series of by-products are linked together and they must find place for development as a group or remain as a group amongst the industrial outcasts, discarded under the classification of waste. Each of these groups, moreover, is inseparably connected with other similar ones, both providing ingredients essential to the others and dependent in turn upon the ingredients the others provide. Thus, from offering so many simple, direct, individually distinct lines of procedure, the conversion of a country's raw resources has come to constitute a vast industrial labyrinth of ramifying, interconnecting, and interdependent chemical procedures, the whole constituting the industrial fabric of the country, and, incidentally, the basis for what the individual has of material comfort and prosperity. The channels do not follow chance directions at random; in so far as they are opened up, they follow courses mapped far in advance by chemical research. Just in proportion as the opening up and maintenance of these channels of interdependence is provided for in accordance with the advances of chemical research, efficiency, conservation, and stability are assured to industrial development; and, conversely, just in the proportion that the necessary provisions are not looked to consistently as an obligation of fundamental importance to national existence, inefficiency, wastefulness, instability, and subservience are bound to remain characteristics in the industrial life of a country. America offers no exception.

Public opinion has of late been disposed to manifest a special degree of interest in speculating on the stability of the current industrial expansion within the United States, once world conditions have again been restored to normal. With industrial life as with other forms, static condition is impossible short of death. The question is not one of whether or not American industrial activity will be able to hold what it has, but that of whether or not it will continue to expand or presently begin to lapse. The expanding coal-product industry is the one most frequently mentioned in this connection. The answer is that a coal-product industry is not the outcome of vacillating chance.

The chance of current events has given rise to a special opportunity, a most extraordinarily auspicious one, in fact, but unless or until the employment of scientific guidance in the commercial following of the trails blazed by scientific exploration becomes an ingrained principle in the directorship of industry, both governmentally and privately, American industrial progress is bound to go astray and fail through inefficiency when exposed once more to the test of competition against the developments from consistent scientific guidance abroad, excepting where, as in the past, natural advantages of resource have been sufficiently great to overcome the handicap of miscontrol. Coal-product manufacture, despite the advantage of enormous resources, has not been able to make place for itself in this latter category.

The present opportunity is a passing one and one which, it is to be hoped, despite the advantages afforded, will not recur soon. To impart stability to the expansion it has given rise to, public opinion must recognize that what in the last analysis is best for the industries engaged in converting the resources of the country into usable form, is also in the last analysis best for the individual, and then act accordingly. Once that realization is fully established, and no clearer illustration of its truth could be desired than that afforded by the coal-product situation, the nature of the resultant action is foreordained. It will lie in the direction of scientific control of chemical industries. Lack of it has been the stumblingblock for American enterprise in the past, and continuance along the old lines of procedure implies a negative answer to the popular question as to whether expansion of the chemical industries in general, and the coal product one in particular, will continue toward an adequate realization of their enormous potentiality following the world's return to normal conditions. This means the relapse to a state of industrial instability, inefficiency, wastefulness, and subservience, a calamatous prospect when the magnitude of the opportunity at hand is considered. Hope looks toward the establishment of a definite economic policy giving the encouragement of an appreciative and understanding public support in the coordination of industrial development.

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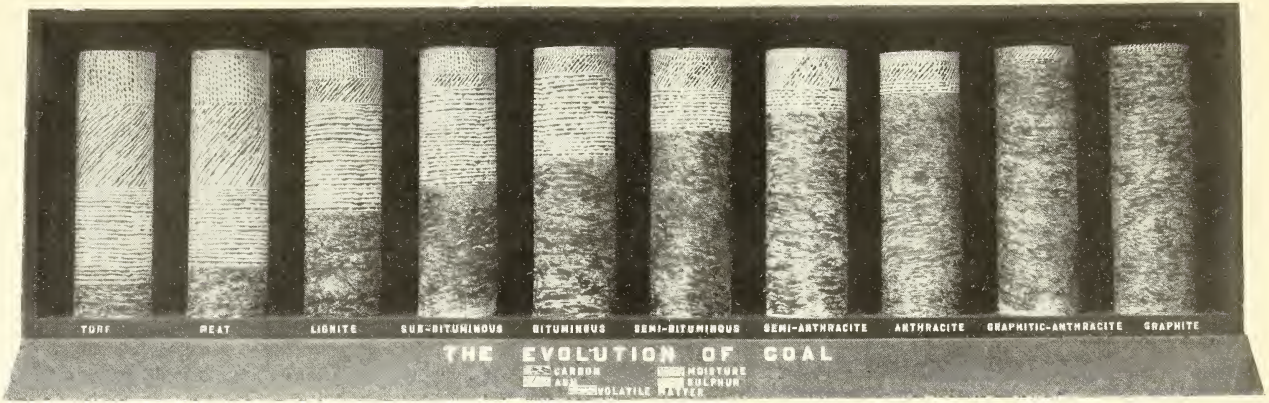
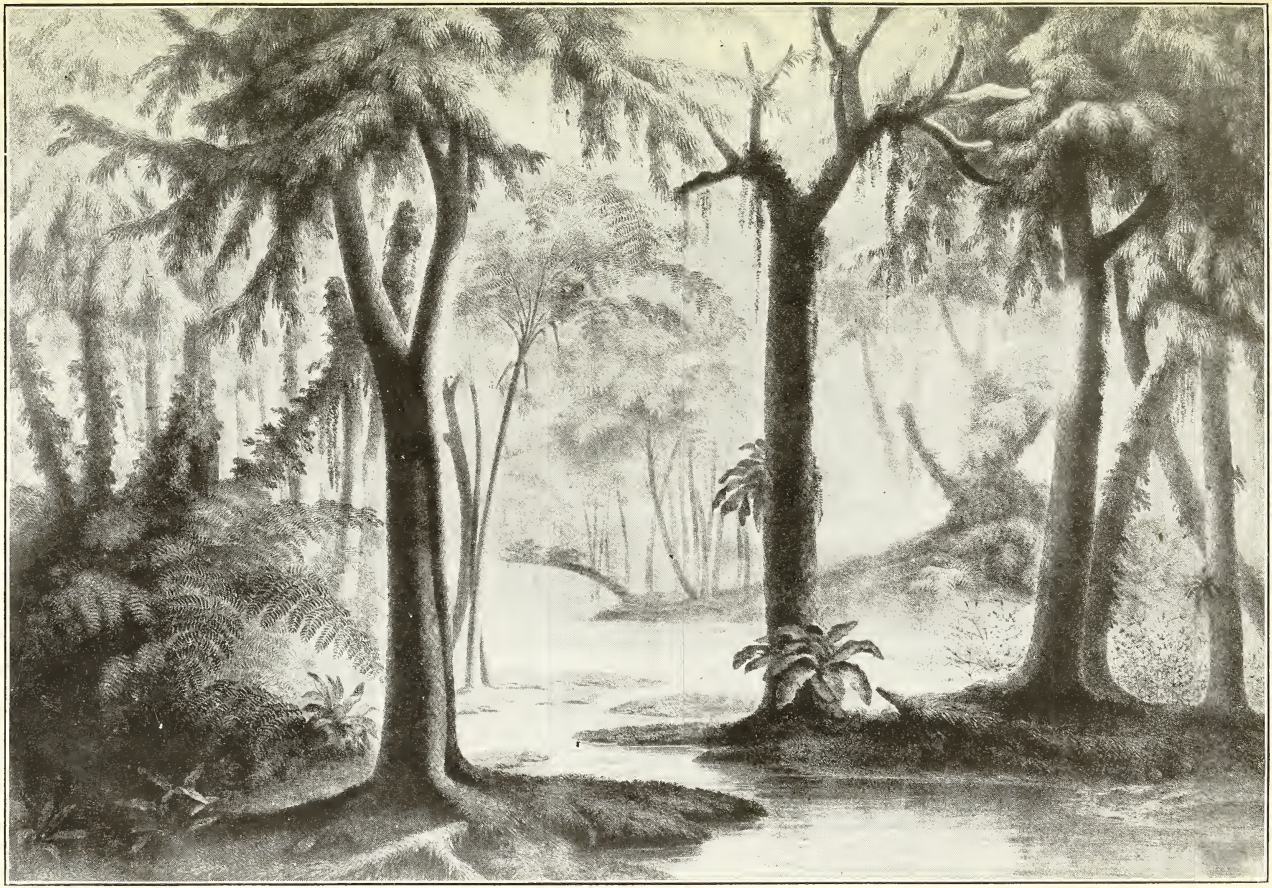

TURF
PEAT
LIGNITE
SUB-BITUMINOUS
BITUMINOUS
SEMI-BITUMINOUS
SEMI-ANTHRACITE
ANTHRACITE
GRAPHITIC-ANTHRACITE
GRAPHITE
THE EVOLUTION OF COAL
CARBON
ASH
VOLATILE MATTER
MOISTURE
SULPHUR

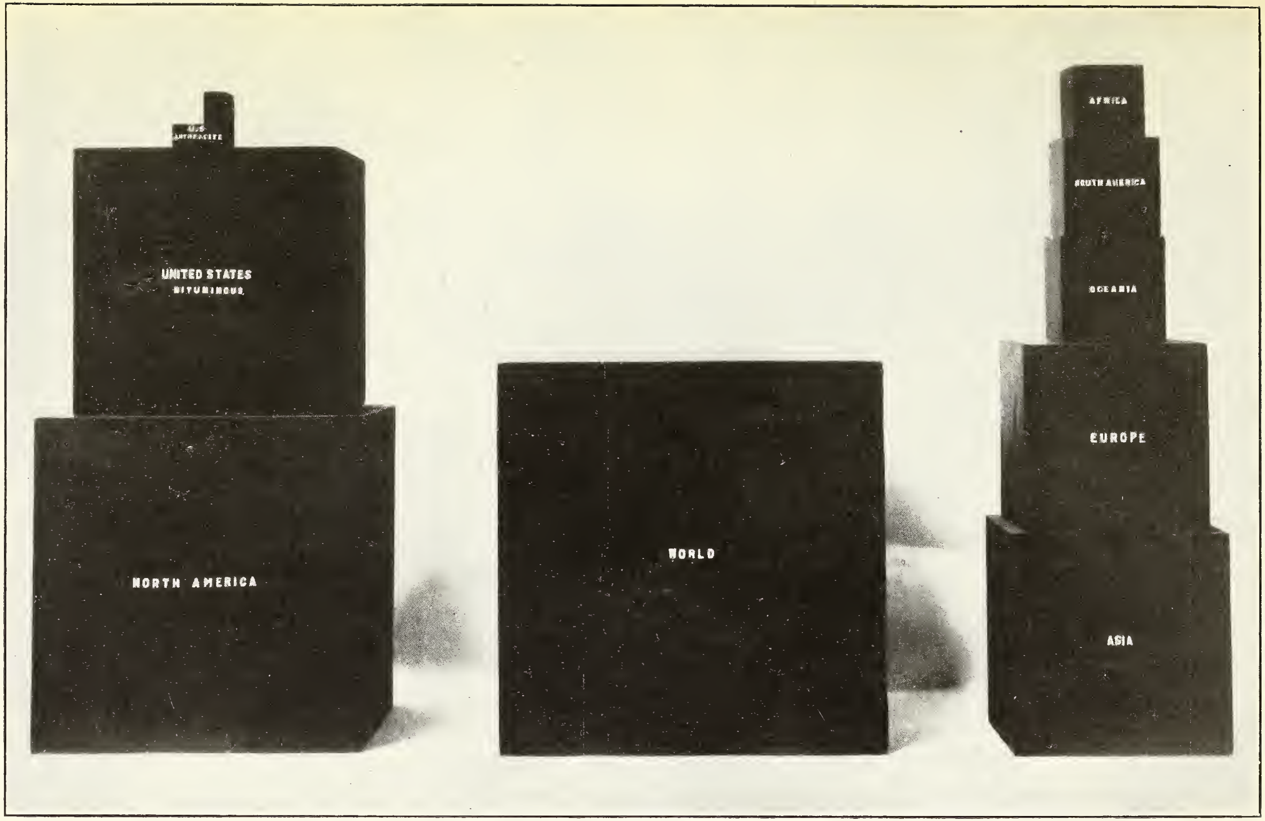
ORIGIN AND DEVELOPMENT OF COAL.

This exhibit shows the successive chemical stages in the evolution of coal. The striking qualities of the original are lost in the reproduction through the use of designs in the place of realistic coloring, but the effect is retained sufficiently to indicate the nature of the sequence and the directness with which it leads back to an origin in vegetal accumulations. The evolutionary process is seen to take the form of increasing density through the progressive expulsion of volatilizable matters in the course of geologic time. This inference is substantiated beyond reasonable question by the actual presence of organic remains in coal beds.



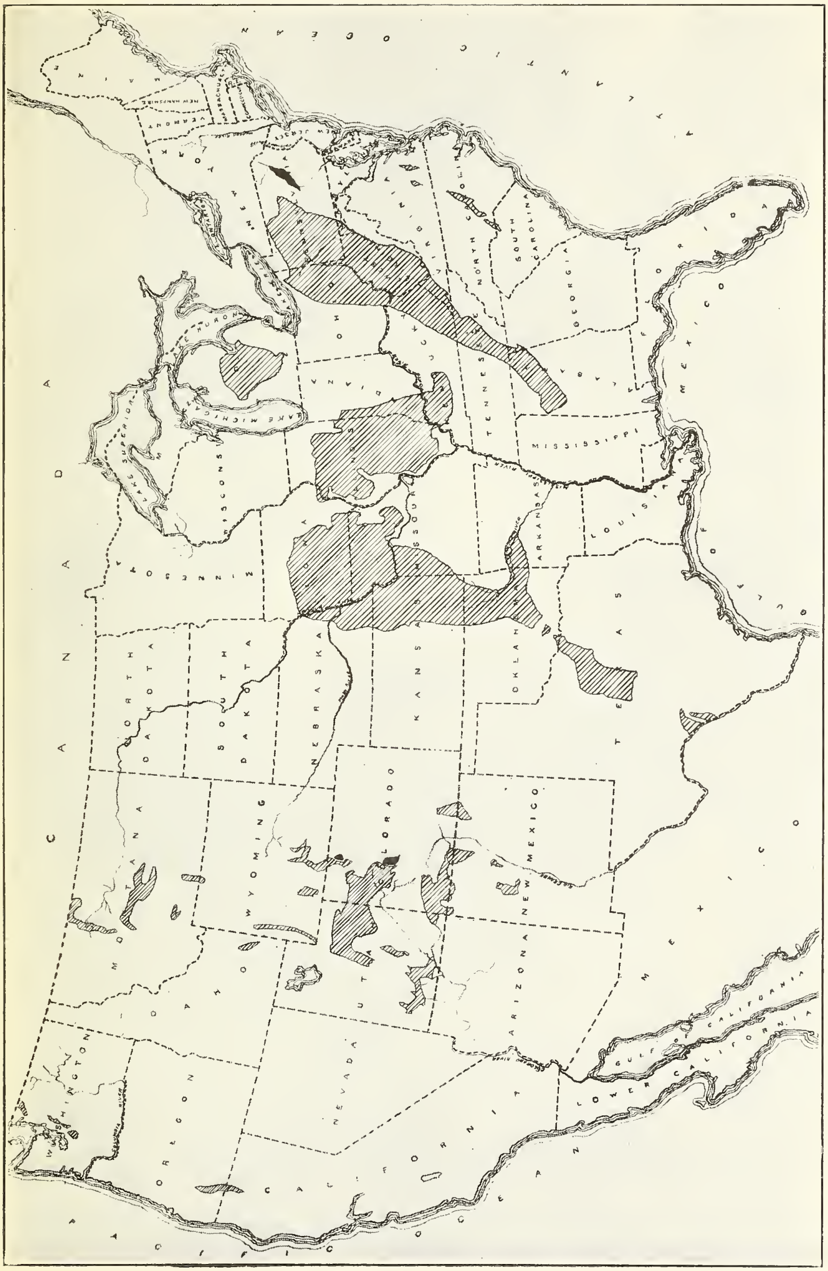
COAL PERIOD LANDSCAPE.

The first stage in the evolution of a coal bed.


U. S.
ANTHRACITE
UNITED STATES
BITUMINOUS
NORTH AMERICA
WORLD
AFRICA
SOUTH AMERICA
OCEANIA
EUROPE
ASIA

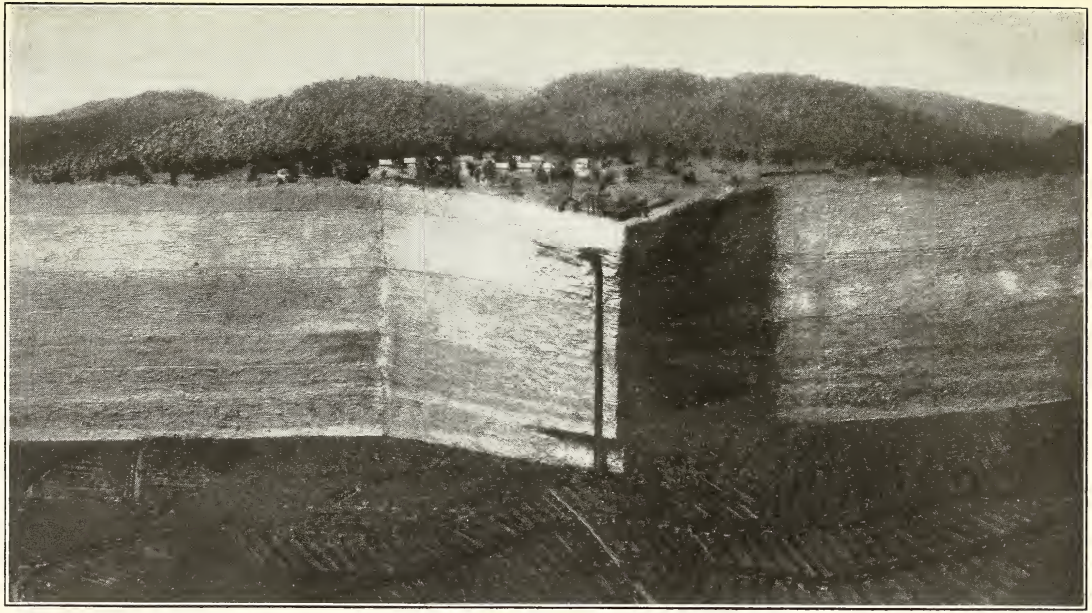
CONTINENTAL DISTRIBUTION OF COAL.

This exhibit represents how the world's coal supply is apportioned amongst the different continents; also the portion contained in the United States. What is missing from the anthracite cube represents the approximate consumption to date.


CANADA
ATLANTIC OCEAN
GULF OF MEXICO
MEXICO
PACIFIC OCEAN
GULF OF CALIFORNIA
LOWER CALIFORNIA
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
MAINE
NEW HAMPSHIRE
VERMONT
MASSACHUSETTS
NEW YORK
NEW JERSEY
PENNSYLVANIA
OHIO
VIRGINIA
KENTUCKY
NORTH CAROLINA
SOUTH CAROLINA
TENNESSEE
GEORGIA
FLORIDA
ALABAMA
MISSISSIPPI
LOUISIANA
ARKANSAS
INDIANA
ILLINOIS
MICHIGAN
WISCONSIN
MINNESOTA
IOWA
MISSOURI
KANSAS
NEBRASKA
OKLAHOMA
TEXAS
NORTH DAKOTA
SOUTH DAKOTA
MONTANA
WYOMING
COLORADO
NEW MEXICO
ARIZONA
UTAH
IDAHO
NEVADA
WASHINGTON
OREGON
CALIFORNIA

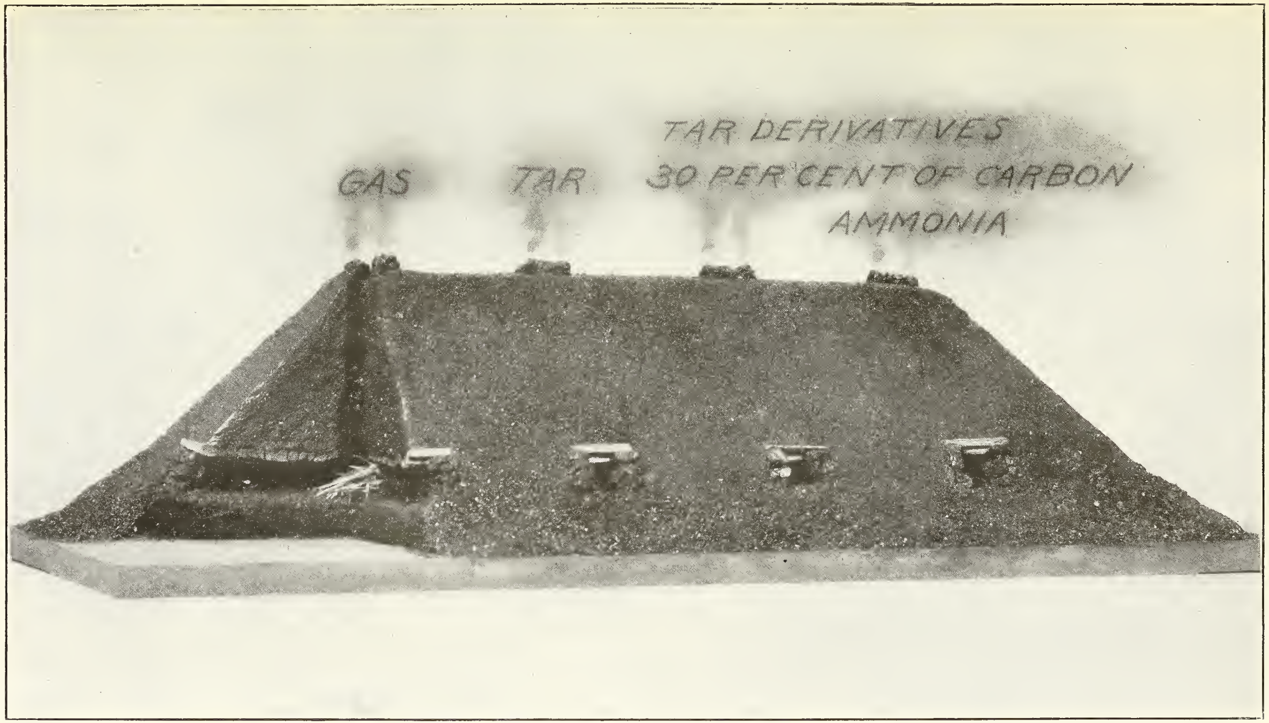
Distribution of Coal in United States.

Map showing the known distribution of anthracite (black areas) and of bituminous coal (hatched areas). The contrast afforded is impressive in view of the importance now attached to the former.



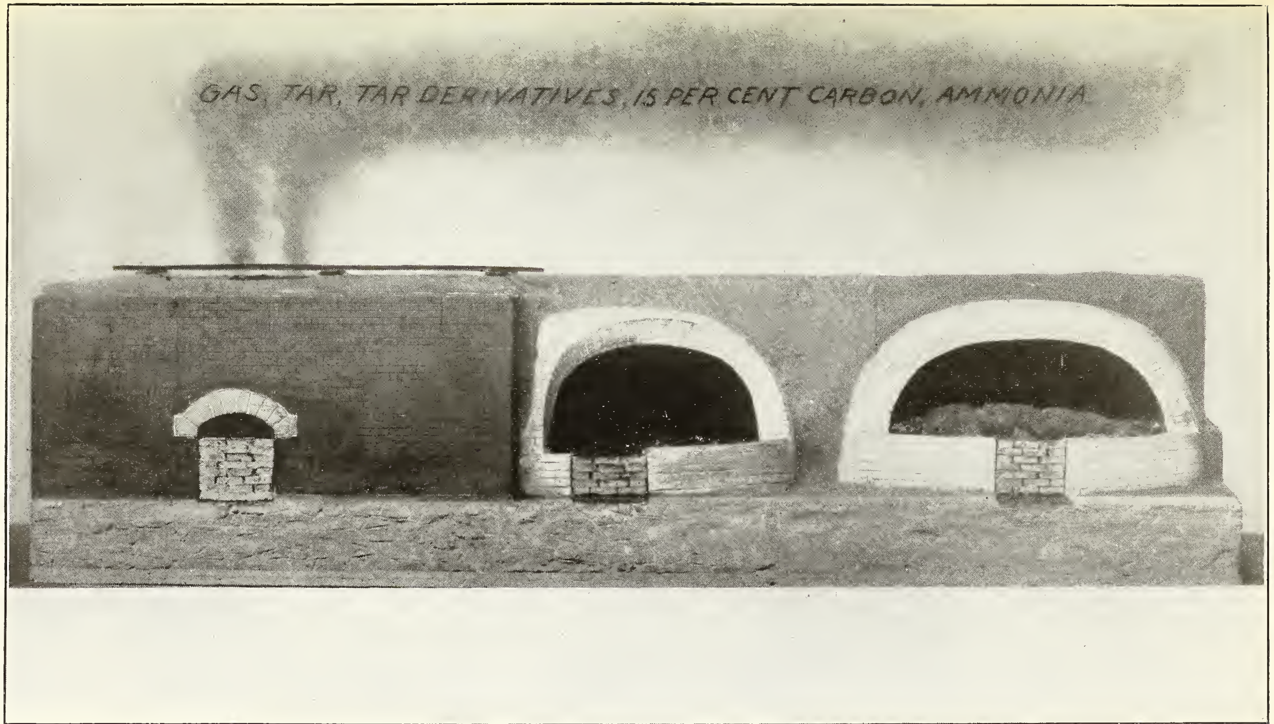
Occurrence and Mining of Coal.

The rock layers or strata above are shown cut through vertically and removed, leaving a flat extent of coal exposed. Tipple, shaft, and layout of haulageways and mining operations are to be seen in their proper relationship. To the left and extreme right are operations in progress in solid coal, but near the shaft the coal has been largely removed excepting for the ribs left to support the overlying rock. The thickness of the coal bed is represented in the height of these ribs, and its conformity of relationship with the layers or strata of commoner sedimentary rock associated with it is apparent in the section through the rock above. From a model donated by the Western Coal and Mining Co. of a mine at Jenny Lind, Arkansas, and in the coal products exhibit of the United States National Museum.


GAS
TAR
TAR DERIVATIVES
30 PER CENT OF CARBON
AMMONIA

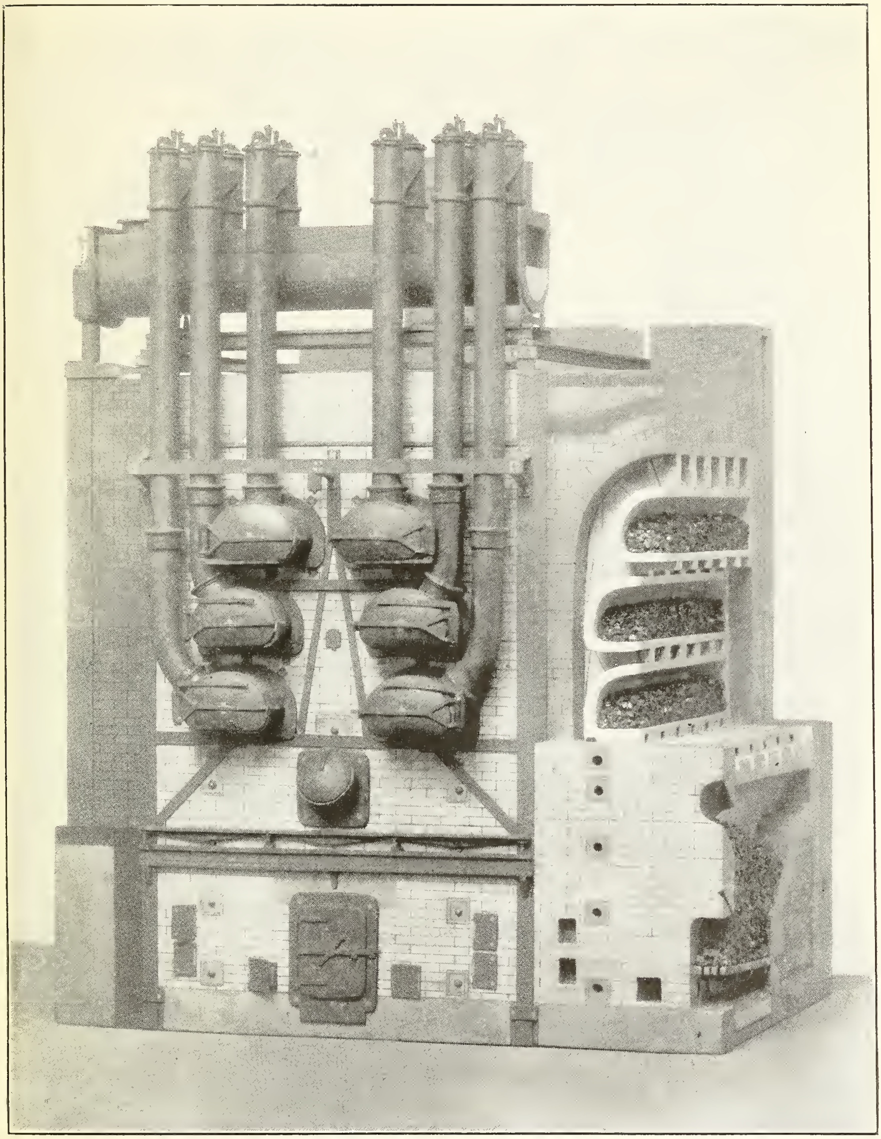
BENNINGTON COKE PILE.

Earliest American method in the coking of coal, supplanted by the inclosed oven of the beehive type. The procedure started with an open heap of coal provided with a system of draught as shown in the portion removed. The fire was kindled under the vertical flues and combustion was kept smothered by banking with powdered coal. From a model in the coal products exhibit of the United States National Museum.



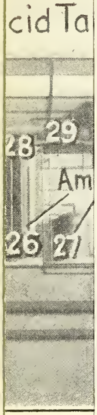
BEEHIVE COKE OVEN.

Oven coking typified in the beehive oven. An oven is charged through the top with 5 tons of coal, filling it to the height of the brickwork in the front opening, and the charge gradually brought to distillation temperature by the heat communicated from adjoining ovens. The escaping gases ignite and, burning in the dome of the oven, increase the heat, thus continuing the process of contributing heat as that in the adjoining ovens diminishes. The entrance for air, being above the coal bed, combustion is kept confined largely to the volatile matters as they distil in the dome. After 48 or 72 hours the residual coke is quenched with water, withdrawn, and a fresh charge of coal introduced. Relative simplicity of construction and operation, coupled with excellence of product, are its advantages; and it is only slowly giving place to modern developments. Its disadvantages, on the other hand, as indicated in the illustration are intolerable to enlightened society. From a model in the United States National Museum.



GAS RETORT BENCH.

A complete bench of six retorts and adjoining one sectioned showing operative features. Coal is charged into the retorts, about 200 pounds to each retort, and the doors closed tightly. When heated from the coke fire below, the volatile ingredients break away, and are carried off for further dissociation into gas, tar, and ammonia. The residual coke is then withdrawn for use primarily in maintaining the temperature of the retorts and secondarily as a by-product. The gas bench is thus of the by-product recovering order so far as the volatile portion of the coal treated is concerned, but the quality of coke is inferior; so in advantages and disadvantages alike it presents the exact reverse of the beehive coking procedure. From a model in the United States National Museum.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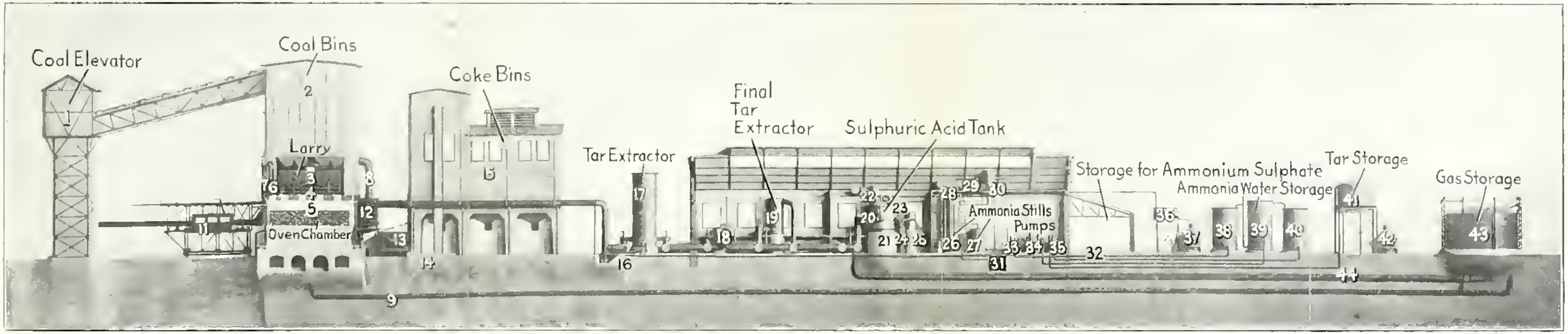


BY-PRODUCT COKING OPERATIONS BY THE KOPPERS SYSTEM.

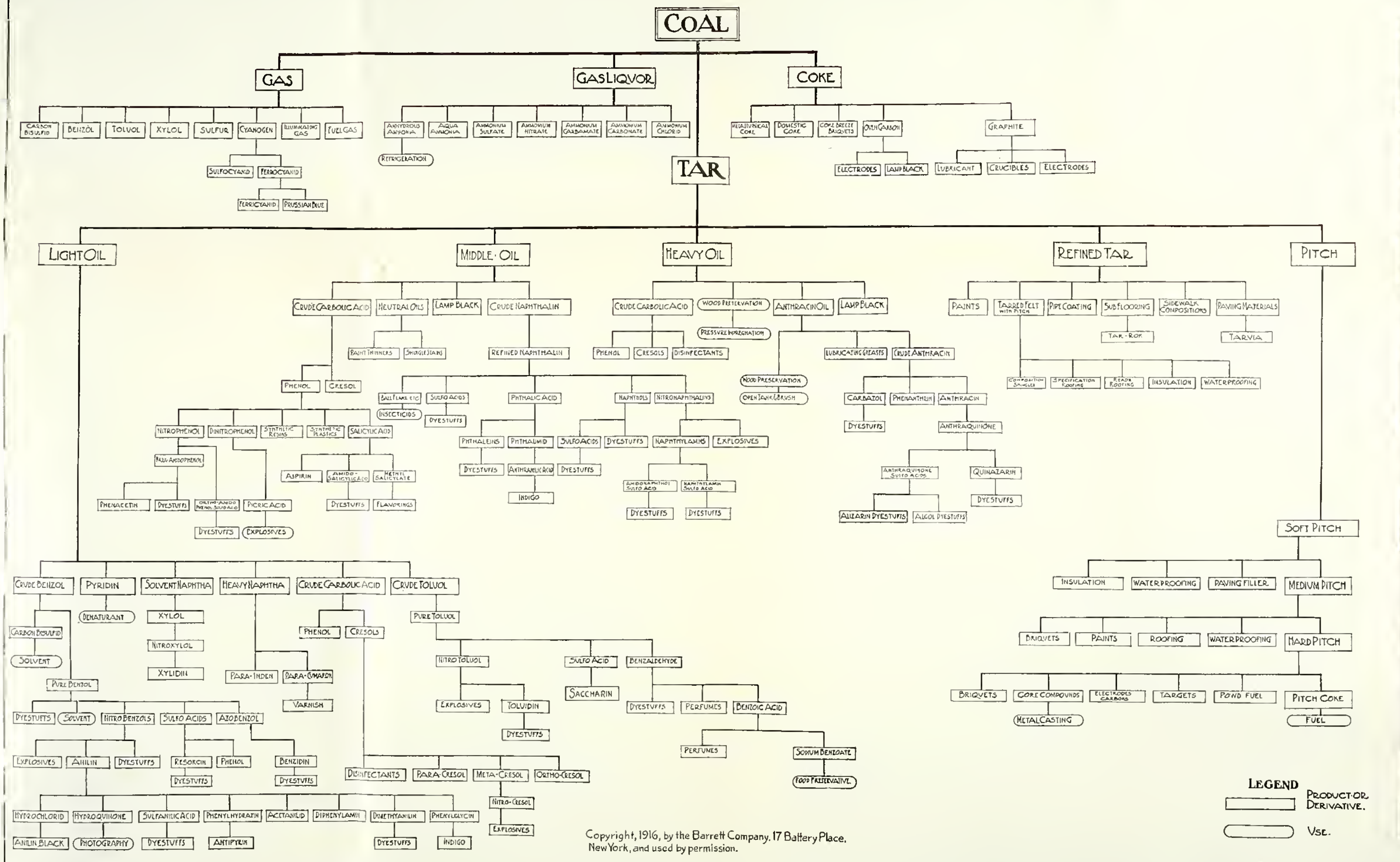
From a relief panel in the coal products exhibit of the United States National Museum. Beginning at the left-hand end of the illustration, the coal hoist (1) elevates the coal to the bins (2) provided with chutes, through which it is fed, as required, into the charging car or larry (3). The larry, in turn, is provided with chutes corresponding to a series of openings (4) in the oven chamber (5). The ovens are long narrow rectangular chambers some 30 feet long, 20 inches wide, and 6 feet high, placed side by side in batteries of 50 or more. Thus an entire battery may be charged by a single larry operating along a track on top, and from a single storage bin. On another track in front of the battery a device known as a coke pusher (11) moves too and fro, opening doors in the front ends of ovens and pushing the finished coke out along a guide (12) to a car (13), both of which operate along the back end of the battery in coordination with the pusher. From the car the coke is dumped into the pit (14) from which it is elevated to the bins (15) for screening and sizing preliminary to shipment or use in associated metallurgical operations as the case may be. The gases ascend through pipes (6 and 7) into a main (8) leading to the sump (16), where the liquors condensing in transit are drawn off. Continuing through the tar extractor (17) the gases are forced by the exhauster (18) through the final tar extractor (19), and thence through the preheater (20) into the sulphuric acid tank or saturater (23) where the free ammonia in the gases combines with the acid to form ammonium sulphate. The purified gas is then piped (44) to the gas holder (43). The liquid from the saturater passes through the acid separator (22), whence the excess acid removed goes to the acid pot (24) for return to the saturater, and the acid-free liquor containing ammonium compounds to the centrifugal drier (21). Here the sulphate is solidified ready to go to the storage bin (32) for shipment. The solution of dilute ammonium compounds other than the sulphate removed, then joins the fixed ammonia liquor derived from the crude liquors concentrating at the outset of operations and draining off into the sump (16). From the sump the crude liquor has meanwhile been pumped to the tar-separating tank (39), whence the tar removed goes to the storage tank (40) and thence to the tar-shipping storage tank (41). The dilute ammonia liquor separated from the tar in 39 goes to the ammonia storage tank 38, whence it is pumped to the tank 28. Passing thence through the free ammonia still (26), the free ammonia is removed, and in the fixed ammonia still (27), where it is joined by the liquor from the sulphate operation, the ammonia in combination is set free so that it too may be recovered by returning the liquor through 26. From 26 the free ammonia liquor goes to the return flow cooler (30), thence through the final cooler (29) to the shipping tank (36).

The most impressive single feature in the whole procedure, as outlined above, is the purely mechanical progress of the operations throughout their elaborate complexity. It is this which, on the one hand, has made the cost of construction warrantable and which in turn involves a magnitude of operations requiring the development of great industrial enterprises before the potentialities toward practicable conservation of natural resources it affords can become attainable.

BENZO

ompa

DIAGRAM OF THE PRODVCTS DERIVED FROM COAL AND SOME OF THEIR VSES


COAL
GAS
CARBON BISULFID
BENZOL
TOLUOL
XYLOL
SULFUR
CYANOGEN
SULFOCYANID
FERROCYANID
FERRICYANID
PRUSSIAN BLUE
ILLUMINATING GAS
FUEL GAS
GAS LIQVOR
ANHYDROUS AMMONIA
REFRIGERATION
AQUA AMMONIA
AMMONIUM SULFATE
AMMONIUM NITRATE
AMMONIUM CARBAMATE
AMMONIUM CARBONATE
AMMONIUM CHLORID
COKE
METALLURGICAL COKE
DOMESTIC COKE
COKE BREEZE BRIQVETS
OVEN CARBON
ELECTRODES
LAMP BLACK
GRAPHITE
LUBRICANT
CRUCIBLES
ELECTRODES
TAR
LIGHT OIL
CRVDE BENZOL
CARBON BISULFID
SOLVENT
PURE BENZOL
DYESTUFFS
SOLVENT
NITRO BENZOLS
EXPLOSIVES
ANILIN
HYDROCHLORID
ANILIN BLACK
HYDROQUINONE
PHOTOGRAPHY
SULFANILIC ACID
DYESTUFFS
PHENYLHYDRAZIN
ANTIPYRIN
ACETANILID
DIPHENYLAMIN
DIMETHYANILIN
DYESTUFFS
PHENYLGLYCIN
INDIGO
DYESTUFFS
SULFO ACIDS
RESORCIN
DYESTUFFS
PHENOL
AZOBENZOL
BENZIDIN
DYESTUFFS
PYRIDIN
DENATURANT
SOLVENT NAPHTHA
XYLOL
NITROXYLOL
XYLIDIN
HEAVY NAPHTHA
PARA-INDEN
PARA-CUMARON
VARNISH
CRUDE CARBOLIC ACID
PHENOL
CRESOLS
DISINFECTANTS
PARA-CRESOL
META-CRESOL
NITRO-CRESOL
EXPLOSIVES
ORTHO-CRESOL
CRVDE TOLVOL
PURE TOLUOL
NITRO TOLUOL
EXPLOSIVES
TOLUIDIN
DYESTUFFS
SULFO ACID
SACCHARIN
BENZALDEHYDE
DYESTUFFS
PERFUMES
BENZOIC ACID
PERFUMES
SODIUM BENZOATE
FOOD PRESERVATIVE
MIDDLE · OIL
CRUDE CARBOLIC ACID
PHENOL
NITROPHENOL
PARA-AMIDOPHENOL
PHENACETIN
DYESTUFFS
ORTHO-AMIDO PHENOL SULFO ACID
DYESTUFFS
DINITROPHENOL
PICRIC ACID
EXPLOSIVES
SYNTHETIC RESINS
SYNTHETIC PLASTICS
SALICYLIC ACID
ASPIRIN
AMIDO-SALICYLIC ACID
DYESTUFFS
METHYL SALICYLATE
FLAVORINGS
CRESOL
NEUTRAL OILS
PAINT THINNERS
SHINGLE STAINS
LAMP BLACK
CRUDE NAPHTHALIN
REFINED NAPHTHALIN
BALL FLAKE ETC
INSECTICIDS
SULFO ACIDS
DYESTUFFS
PHTHALIC ACID
PHTHALEINS
DYESTUFFS
PHTHALIMID
ANTHRANILIC ACID
INDIGO
NAPHTOLS
SULFO ACIDS
DYESTUFFS
DYESTUFFS
NITRONAPHTHALINS
NAPHTHYLAMINS
AMIDONAPHTHOL SULFO ACID
DYESTUFFS
NAPHTHYLAMIN SULFO ACID
DYESTUFFS
EXPLOSIVES
HEAVY OIL
CRUDE CARBOLIC ACID
PHENOL
CRESOLS
DISINFECTANTS
WOOD PRESERVATION
PRESSURE IMPREGNATION
ANTHRACIN OIL
WOOD PRESERVATION
OPEN TANK & BRUSH
LUBRICATING GREASES
CRUDE ANTHRACIN
CARBAZOL
DYESTUFFS
PHENANTHRIN
ANTHRACIN
ANTHRAQUINONE
ANTHRAQUINONE SULFO ACIDS
ALIZARIN DYESTUFFS
ALGOL DYESTUFFS
QUINAZARIN
DYESTUFFS
LAMP BLACK
REFINED TAR
PAINTS
TARRED FELT WITH PITCH
COMPOSITION SHINGLES
SPECIFICATION ROOFING
READY ROOFING
INSULATION
WATERPROOFING
PIPE COATING
SUBFLOORING
TAR-ROK
SIDEWALK COMPOSITIONS
PAVING MATERIALS
TARVIA
PITCH
SOFT PITCH
INSULATION
WATERPROOFING
PAVING FILLER
MEDIUM PITCH
BRIQVETS
PAINTS
ROOFING
WATERPROOFING
HARD PITCH
BRIQVETS
CORE COMPOUNDS
METAL CASTING
ELECTRODES CARBONS
TARGETS
POND FUEL
PITCH COKE
FUEL
LEGEND
PRODUCT OR DERIVATIVE.
VSE.
DDD-5 12 16

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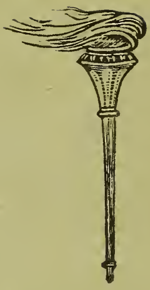

SMITHSONIAN INSTITUTION
UNITED STATES NATIONAL MUSEUM
Bulletin 102, Part 2

THE MINERAL INDUSTRIES OF THE UNITED STATES

FERTILIZERS: AN INTERPRETATION OF THE SITUATION IN THE UNITED STATES

BY

JOSEPH E. POGUE
Of the Division of Mineral Technology
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WASHINGTON:
GOVERNMENT PRINTING OFFICE
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BULLETIN OF THE UNITED STATES NATIONAL MUSEUM
Issued October 10, 1917.

FERTILIZERS—AN INTERPRETATION OF THE SITUATION IN THE UNITED STATES.

By Joseph E. Pogue,
Of the Division of Mineral Technology, United States National Museum.

INTRODUCTION.

Eighty-odd chemical units or elements are known which singly or in various combinations make up all objective things. Certain of them are essential to life, as entering into the constitution of the body itself; others are necessary to the upward development of life in that they comprise those materials through the use of which evolving man has developed his mentality; still others seemingly play no part in human affairs.

The first are chiefly products of the soil and come to man in the form of food; the second are products of the rocks and are obtained by man in the form of minerals; the third have no apparent use, and we are not concerned with them here, however interesting might be speculations as to their significance.

In the final economy of nature, therefore, those chemical elements that enter into the food supply are of fundamental importance, while next to them are those which, combined as mineral products, have been employed by mankind in building his civilizations.

At the outset primitive man was predatory, living chiefly on other animals. He was, therefore, not immediately concerned with the products of the soil, although ultimately and indirectly his sustenance came from that source. At a later stage, however, he turned his attention to the raising of crops and thereby made possible a permanence in settlement and increase in population not attainable under the precarious and shifting circumstances of an exclusive game supply. It is now regarded as a long step upward in the progress of man when he started his first crude attempts at agriculture. Whether early man so viewed it himself is doubtful, inasmuch as this form of activity was to him ignoble and therefore relegated to women, the aged, and the infirm.

Many thousands of years have passed since the first simple beginnings in agriculture. Progress was made, very notable progress in some instances, particularly along mechanical lines, as in irrigation, terracing, the prevention of erosion, and the like; some advances were even realized in the use of artificial accelerators or fertilizers. But agriculture remained a rule-of-thumb procedure, locally effective because based on accumulated experience, yet broadly inefficient, until the development of modern chemistry gave a foundation of exact knowledge upon which further advance could be built.

Scientific agriculture came to the western world none too soon. It made possible the growing population essential to industrial development—a population increasing at a rapid rate because no longer held down by the waves of pestilence that swept over Europe before the days of preventive medicine. In the East, grim nature has periodically lopped off the excess of population by depressions in soil productivity; and there to-day this inexorable process continues among the hordes of India and China. At the present moment a new and unnatural factor has come to upset the balance in the West—the World War has placed an increased and unprecedented burden upon intensive and scientific agricultural development. As at first, so to-day, the securing of an adequate food supply is the most pressing problem that faces mankind.

The amount of food that may be realized from any region depends upon two obvious factors—the area of soil and its fertility. In a new or pioneer country land is plentiful, and the need of an increasing food supply for a growing population is met at first by enlarging the area cultivated; but, sooner or later, there comes a time when further enlargement is impossible and food must be imported or else the yield of the soil must be increased by artificial means. The world has already reached the stage where in all regions of dense population the latter is imperative—a fact which should have the widest and most thorough appreciation.

THE THEORY OF FERTILIZERS.

Various means of increasing soil productivity are practiced, but the most important gain is attained by adding certain products directly to the soil. These substances are the so-called fertilizers. A glance at the nature of soils and the chemical reactions that take place in them to produce plant growth will make clear the part that fertilizers play in accomplishing their important function.[1]

To begin with, soil does two things: It forms a mechanical medium for supporting and protecting the growing plant, and it supplies the plant with some of the chemical material to be built into its structure.

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[1] It is, perhaps, needless to say that this will be outlined in the most general way only. To go into the matter in technical detail would involve material inappropriate for the present purpose. The theory of fertilizers is by no means thoroughly understood.

The rest of its substance the plant obtains from the air, from moisture, and from the bacteria present in the soil, although the last may be regarded as part of the soil itself.

The chemical material contributed by the soil focuses our interest here—the calcium, the phosphorus, the sulphur, the nitrogen, the potassium, the sodium, the magnesium, the iron, and some others. These substances are not present in their elemental or simple condition, but as compounds available for transfer into the body of plants.

These elements are likewise present in the solid rocks that everywhere underlie the soil, but in combinations wholly unfitted for sustaining plant growth. They must first be rendered suitable by the general process of natural rock decay called weathering, which mechanically reduces the solid rocks to the consistency of soil and chemically prepares their components for the sustenance of life. The soil then becomes the laboratory in which the gases of the atmosphere, with water, and certain constituents of decayed rock are combined into the organic products, or plants, upon which human life ultimately depends.

In the normal course of events, plants spring up, live their course, and die, giving back to the atmosphere and soil the elements employed in their life cycle. Thus it is that the rank growth of the jungle is unremitting. But where plants are removed by artificial means, the balance is upset and the soil is depleted in respect of some of its essential compounds. But soil is not static; the processes of weathering are continuous, and if the plant removal be stopped for a sufficiently long period, the deficiency will be naturally remedied by the transformation of a further quantity of needed compounds into an available or soluble condition. This result, however, can not be waited for; in populous sections the soil must be cultivated continuously; the elements removed too rapidly must be replaced artificially, that is, by the use of fertilizers. This is an absolute, basic necessity. Fertilizers, indeed, play a more fundamental part than that of merely increasing yields and profits; no soil can be cultivated continuously without their use.

Fertilizers, moreover, have an application beyond that of making possible continuous and intensive cultivation; by their use, many soils can be rendered fertile which are deficient in one or more essential constituents by virtue of peculiar geologic history. Thus fertilizers extend the possibilities of food production to great areas unfitted by nature for productive yield.

These considerations of the social value of fertilizers are aside from the economic advantage of their use as leading to greater profits to the acre and greater yields to the unit of labor expended. Yet this economic advantage is the great motive force which, under existing conditions at least, must be counted upon to carry fertilizer utilization to its proper realization.

By long experience, it has been found that those elements of which the soil is most quickly depleted are nitrogen, phosphorus, and potassium; and therefore compounds of these elements are the chief ingredients of the commercial fertilizers. Calcium, in the form of lime or crushed limestone, is added with favorable results to some soils; but this is more to counteract or neutralize a high acidity or "sourness" than to contribute a needed constituent,[1] and since, moreover, limestone is so widely distributed that an organized industry is not necessary to supply it, this substance will not be considered in further detail in this paper. Sulphur, in the elemental condition, has recently come to the front as a fertilizing material of some promise, but its use, as well as that of sulphuric acid on the alkali lands of the West, may be said to be still in an experimental stage. The fertilizer industry, therefore, as it exists at present, is concerned with the preparation of suitable compounds of nitrogen, phosphorus, and potash to form commercial fertilizers, which are distributed for immediate addition to the soil. The securing of an adequate supply of raw materials, and the development of a wider and more intelligent use of fertilizers, are two problems of the utmost importance, especially at the present moment, when the World War endangers certain of the supplies and at the same time necessitates an increased yield in food.

The chart accompanying this paper is designed to present in graphic form, in a single expanse, the normal fertilizer situation in the United States and the significant effects that the present war has exerted upon this situation. It will serve to set forth in their *true proportions* the relative importance of the many sources of supply, both domestic, foreign, and potential, that go to make up the manufactured product; and to remove the disproportionate weight that has attached to some of them as a result of undue publicity.

THE RAW MATERIALS OF FERTILIZERS.

PHOSPHORUS.

Phosphorus, in the elemental condition, is a very active substance, but in the form of compounds present in the soil it loses its vigor and enters quietly into the structure of plants and through them into animals. In the former it is found in largest quantity in the seed and fruit; while in the latter it is an important constituent of bone and is present also in the brain and associated nervous matter. To man, therefore, it is particularly important. Soils containing no compounds of phosphorus or else depleted of those once present, demand an addition of such material to be productive.

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[1] In some soils, lime and limestone set up chemical reactions which render the potash and phosphorus more available, and also facilitate the growth of nitrogen-fixing bacteria; so that in such instances these materials have an indirect fertilizing value.

The basis of commercial fertilizers and the ingredient of greatest bulk to which the other more concentrated constituents are added, is an impure compound of phosphorus occurring in nature in large masses and known as phosphate rock. The United States is the world's greatest producer of this material, and within her borders lie the largest reserves thus far discovered. Some 10 years ago the quantity of phosphate rock in sight throughout the world was not sufficient to meet the growing agricultural needs for 100 years, and the situation was said to represent "man's weakest hold on the universe"; but the recent discovery of our western phosphate fields and an appreciation of the size of deposits in northern Africa have extended this limit many centuries hence.

There are other sources of the phosphorus content of fertilizers, among which organic substances such as fish scrap, cottonseed meal, bones, slaughterhouse refuse (prepared and sold in a form called tankage), and guano are the most important; but most of these substances are in strong demand for other purposes, and the growing price is fast reducing their economic availability for fertilizer manufacture. This, too, in spite of the fact that most of them have also a nitrogen content and therefore perform a double function when added to fertilizers.

At the outbreak of the European war, we were obtaining from abroad, in addition to a small importation of phosphate rock, inconsequential supplies of two other phosphatic products. These were basic or Thomas slag and the mineral apatite. Basic slag is a by-product from the smelting of iron ores rich in phosphorus, by a process which relegates this usually deleterious constituent to a mass of slag which is thereby so enriched in phosphorus that it can be ground and used as a fertilizer. This process has developed principally in Europe, where large deposits of phosphorus-rich iron ore have been rendered available by it; in fact, the iron supply of Germany is drawn largely from such deposits in Lorraine, divided between German Lorraine and captured French Lorraine, which have also furnished most of the phosphate fertilizer used in Germany since the supply of phosphate rock from the United States was cut off. Apatite is a mineral mined to a limited extent in Canada; but its deposits are too restricted in size ever to be significant, in spite of the fact that scattered microscopic crystals of apatite are present in practically all igneous rocks and represent the ultimate source of the phosphoric acid or soils as well as of that now found concentrated in phosphate rock.

In the United States, therefore, phosphate rock is and must remain the dominant source of fertilizer phosphorus. The chief producer at present is Florida, which contributes normally 75 per cent of our annual output of 3,000,000 tons. There this material forms three types of deposits, known as rock phosphate, pebble phosphate, and soft phosphate; but all are essentially flat-lying, superficial beds of solid rock or loose, bowldery material, representing chiefly a concentration of phosphatic substance through the superior solubility and removal of the associated rock. The nature of these deposits enables them to be economically worked by means of large open pits, and their position near seaboard affords cheap transportation to manufacturing centers such as Savannah, Charleston, Norfolk, and others, as well as ready exportation to Europe.

Other deposits of interest and value as being within reach of the eastern fertilizer centers lie in South Carolina, Tennessee, Kentucky, and Arkansas, but these are smaller in output as well as in reserves, and, with the exception of those in South Carolina, less favorably located than the Florida deposits. All the eastern deposits combined, however, would sustain the increasing domestic consumption but a few decades; and hence unusual interest attaches to the discovery in 1906 that a belt of country, later found to extend from near Salt Lake City in Utah to Helena, Mont., includes a number of beds of phosphate rock. A careful survey of this region by the United States Geological Survey has disclosed a measurable tonnage of phosphate rock far greater than known elsewhere in the world—and the field is not yet thoroughly explored in its entirety—but the material is not high-grade throughout, and the supply, while large, is by no means inexhaustible. The western deposits have not as yet been worked to any significant extent, owing to the fact that there is practically no local demand for fertilizers, while a long and costly freight haul walls off eastern markets. Their development awaits a local need or exhaustion of eastern deposits, but may be accelerated by the successful application of a process now known for extracting the phosphoric acid in concentrated form so as to reduce the freight on unit values. Possibilities of a local phosphate industry are opening up in connection with the manufacture of sulphuric acid from waste smelter gases at such near-by mining centers as Butte, Mont.

The War has seriously affected the phosphate-rock industry, practically cutting off the exports, which in 1913 amounted to 42 per cent of the total production. This burden fell chiefly on Florida, from which the great bulk of the exports was shipped; while Tennessee, in normal times the second largest producer, being little concerned with exports, has actually had a slight industrial advance. The phosphate-rock industry, in general, has suffered an additional setback because of the strong counter demand for sulphuric acid for use in making munitions, raising its price and in turn inducing curtailment in output of phosphate rock.

The coming of peace will undoubtedly rehabilitate the phosphate-rock industry, and will probably bring such increased demands for its product as will rapidly advance its output. The industry may be expected to introduce more efficient methods of mining and handling the rock, in place of the wasteful procedure still followed in many localities, while it should solve the problem of using material of lower grade than practicable under present practice, so as to extend the life of the deposits.

Phosphate rock in the crude condition is not suitable for fertilizer purposes, even if finely ground, because its valuable constituent is bound up in a relatively insoluble form. Hence the crude material is treated with about an equal amount of sulphuric acid, which produces a substance called acid phosphate, in which nearly all the phosphorus has been changed to a form suitable for plant food. The fertilizer industry therefore is closely associated with the manufacture of sulphuric acid, consuming indeed just about half of the several million tons of this material made each year, the rest being utilized in a hundred and one other industries; for sulphuric acid is one of the most widely used of chemical substances.

The need of large quantities of sulphuric acid gives us one key to the localization of the fertilizer industry, since most of the acid used for fertilizer purposes is made from pyrite, a sulphur-bearing mineral, brought in bulk by return bound Mediterranean freighters, which stop at the port of Huelva in Spain and take on as ballast this mineral, mined cheaply in the great mines of Rio Tinto in that country. Another reason for the concentration of the fertilizer industry in the southeastern States is, of course, the fact that the soils there are lean and they also have been long under cultivation and are drained of their plant food.

At the South Atlantic ports, therefore, the pyrite and phosphate rock find their cheapest juncture, and here are the principal plants which roast the pyrite and manufacture its sulphur fumes by a cumbersome process into the strong acid needed to treat the phosphate rock. It is the resultant acid phosphate to which potash and nitrogen compounds are then added to produce the complete commercial fertilizer.

The cutting off, in part, of the supplies of Spanish pyrite by the unrestricted submarine warfare of 1917 has considerably upset the fertilizer industry by endangering its sulphuric acid source; and this condition has led to a limited development of some of the numerous small pyrite and pyrrhotite deposits of the Eastern States, never before able to compete with the Spanish pyrite. It has also directed attention to the sulphur deposits of Louisiana and Texas as a possible source of raw material, although these deposits, while cheaply worked, have been thus far shipped for other uses owing to the purity of their product.

The fate upon return of normal conditions of the numerous small activities that have developed to tide over the present pyrite shortage should merit the serious attention of the United States; for resumption of conditions that delayed the development of these domestic activities will cause their decadence. Moreover, the failure of the Government to formulate a definite policy in regard to just such post-war conditions has evidently retarded the industrial efforts needed as a remedy for current conditions.

NITROGEN.

It is not intended to indicate the relative importance of the three major plant foods by the order in which they are taken up here; their functions, indeed, are different, and they are consequently not open to comparison in this respect. Nitrogen, however, is the element customarily cited first on the labels of commercial fertilizers, and it may conveniently be taken up next. Nitrogen, of course, does not appear in fertilizers in the elemental or gaseous condition, but in the form of various chemical compounds, such as sodium nitrate (also called Chile saltpeter, or merely nitrate), ammonia, ammonium sulphate, and complex organic compounds; all, in short, more or less soluble in the weak acids which operate around the roots of plants and convey the plant food in solution to its destination.

Nitrogen contributes stalk growth to the plant. When it finds its way to the bodies of animals it enters into the composition of the proteid compounds, which are present in every cell, playing a part of essential importance in the life processes. Unlike phosphorus and potassium, nitrogen is not a product furnished by the weathering of rocks, but its source is the atmosphere, which, indeed, is composed to the extent of about 78 per cent of this gas. But so long as neither plants nor animals are adapted for breathing in the required nitrogen direct, a roundabout method has been evolved whereby microscopic organisms known as bacteria, present on the roots of plants, transform the atmospheric nitrogen into compounds of suitable nature for assimilation. A class of plants, the legumes, of which clover is a familiar example, has the ability of fixating nitrogen in this way to an unusual degree; and a crop or so of such plants, when turned back into the soil, form a common expedient for increasing the nitrogen content of farm land.

The most prominent source of nitrogen has long been sodium nitrate, a natural salt occurring in quantity in the deserts of northern Chile. It is found in the form of a thin blanket or bed which under-lies more or less continuously a strip of country inclosed between the Coast Range and the Andes, and extending for several hundred miles southward from the confines of Peru. This occurrence was discovered in 1821, and its exploitation led directly to the Peruvian-Chilean war of 1879–1882, which resulted in the acquisition by the latter country of the coastal portion of Bolivia and the Peruvian province of Tarapacá. Its continued development has made Chile a stable and prosperous nation, as a result of the governmental income from the royalty imposed on exports; and for the past half century the whole world has looked to this locality for its nitrogen supply. Such has been the case because nowhere else on the globe have geological conditions conspired to produce a vast accumulation of nitrogen fixed in usable form. Even here these valuable deposits owe their existence to the total absence of rain.

Chilean nitrate has become of greater importance to the explosive industry than to the manufacture of fertilizer, owing to the fact that it is the chief source of nitric acid used in making practically all explosives. In this connection, however, it should be remembered that explosives are not solely employed in times of war, but their utilization is also widespread in peace time in the blasting operations upon which modern mining and railroad construction depend. Without the Chilean deposits, it would appear, the world would have been deterred for many decades, if not longer, in reaching the point of industrial development in which it is now involved, so far-reaching can be the effect of a single mineral deposit.

The fertilizer industry, therefore, in order to obtain its share of Chilean nitrate, has been forced to meet a price raised by this counter industrial demand and the generous royalty imposed by the Chilean Government, and only mitigated by the provision of nature in rendering the deposits of such character as to be cheaply worked. And when we add to this the recent demands put upon this mineral deposit by the unparalleled needs of the allied Governments in regard to war explosives and consider in addition the circumstance of a constantly decreasing ocean tonnage growing out of the submarine warfare we see that the problem of Chilean nitrate from a fertilizer standpoint is not easy of solution. We gain some idea at the same time why the "nitrogen question," which sprang into prominence over a year ago, still holds well to the forefront.

The fertilizer industry, seeing its most convenient nitrogen source drawn upon by another large industry and then upon the coming of war largely appropriated[1] by that activity, has concerned itself deeply with other sources of supply. The largest source of fertilizer nitrogen, therefore, even before the war, had become a number of organic products, such as tankage, fish scrap, and cottonseed meal, produced in this country, and guano imported from almost depleted deposits off the Pacific coast of South America. But with the coming of war other demands have been put upon most of these products, raising their price. In regard to cottonseed meal in particular, it has gradually become apparent that it is indirect and wasteful to add this material to soil to increase food production when it can be fed directly to cattle to accomplish more effectively the same purpose and then be later recovered in almost its entirety for fertilizing use in the form of manure. It would seem, therefore, that opposing economic demands are gradually withdrawing organic nitrogen of the kinds enumerated from the fertilizer industry.

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[1] Not so much in a numerical as in an economic sense. While such figures as may be obtained seem to indicate that as much Chilean nitrate is going into fertilizers in this country in 1917 as in 1913, the heavy war demands for this substance have worked against its effective (i. e., cheap) utilization in fertilizers.

The third major source of nitrogen, as yet only partly developed, is coal. The nitrogen in coal might be termed fossilized nitrogen in that it represents a portion of the nitrogen of the atmosphere withdrawn in ages past by coal-forming plants and now fixed in the resultant coal to the extent on the average of over 20 pounds of nitrogen to each ton of coal. When the coal is burned this nitrogen is given back to the atmosphere and lost. If the nitrogen were recovered from all the coal consumed throughout the world, the supply would more than suffice the total needs of industry during the era of extensive coal utilization, which is limited, however, to a short period of centuries.

But recovery of nitrogen from all the coal used is an impracticable thing under present usage. In this country in 1913 we saved the nitrogen from only 3 per cent of the coal mined. That figure was perhaps as high as economic conditions permitted at that time; it is a little greater to-day, and it is subject to considerable increase in the future, provided the whole fabric of coal by-product development advances without dismemberment. This will be clearer if we consider that coal at present serves two prime functions—it furnishes fuel to produce heat and power and it supplies the coke required in the process of changing iron ores into metallic iron.[1] Roughly, 12 per cent of the coal mined in the United States in 1913 was made into coke; that is, 69,000,000 tons of coal was so treated. Of this quantity, nitrogen was recovered from only a quarter, yet that nitrogen supplied a significant part of our total needs.

Coke is coal freed of certain liquids and gases which are given off when the coal is heated without access of air. The coke industry grew up many decades ago around Pittsburgh, because of the occurrence of suitable coal in that locality, establishing there our great iron and steel industry. At first the coke was made without regard to saving the volatile portion, the process being carried out in the so-called beehive ovens, which not only waste valuable constituents of the coal but actually consume a considerable part of the coal itself. To say that this method should never have been utilized, or should now be stopped by drastic means, would be to overlook the fact that progress in such matters can scarcely exceed the industrial demands for the products involved. This country is just now in a transitional state in this respect; an increasing amount of coal is being made into coke in a modern type of oven, known as the retort or by-product oven, which not only produces a maximum of coke but at the same time yields gas, nitrogen in the form of ammonia,[1] and coal tar, this last convertible into dyes, medicinal preparations, explosives, and other compounds. Thus the production of nitrogen from coal is closely dependent upon the production of its associated by-products, and is limited at any given time by the demand for coke on the part of the iron industry and the demand for other coal products on the part of other industries. The proper development of coal-product nitrogen must, therefore, go hand in hand with a well-balanced growth of the entire coal-products industry; and to reach its full fruition, must expand beyond the limits imposed by the needs for metallurgical coke through a gradual extension of the uses of coke to fuel and power purposes.

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[1] A minor use of coal is for the manufacture of illuminating gas, but nitrogen is recovered from a relatively low percentage of coal used for that purpose.

But coal-product nitrogen, while the most promising partly developed source of nitrogen in this country to-day and open to considerable and somewhat rapid expansion, must nevertheless remain a transient source, if transient be interpreted to represent a few centuries. The ultimate source, it would seem, upon which the world must eventually depend is the atmosphere. Coal-product nitrogen, indeed, on the last analysis, is merely atmospheric nitrogen rendered more readily available by geological processes of past ages, and is therefore a tide-over from a purely mineral source to the atmosphere.

The world, in fact, is already turning to the atmosphere for a significant part of its nitrogen. Three processes for securing nitrogen from the air have proved successful under different circumstances, and other processes are in the course of experimentation, if not actual development. The three processes which have proved practicable under certain limitations are the arc process, the cyanamid process, and the Haber process.

The arc process produces nitric acid by means of the combustion of nitrogen and oxygen in the electric arc. It requires large quantities of cheap electric power and has proved successful in Norway, where hydroelectric power abounds. Its product for fertilizer use must be neutralized, and the resultant substance, calcium nitrate, is not adaptable to machine distribution as practiced in the United States.

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[1] About a third of this ammonia is used in refrigeration, some 10 per cent in the manufacture of explosives and chemicals, while half or more goes into fertilizers in the form of ammonium sulphate.

The cyanamid process depends upon the combination of nitrogen with calcium carbide; it requires less power than the arc process; and its product, cyanamid, is directly suitable for use as fertilizer or convertible to ammonia compounds. The product may also be oxidized to nitric acid by a process successfully applied abroad. An important cyanamid industry has developed on Canadian soil at Niagara Falls, and the process has met success in Germany.

The Haber process involves the direct synthesis of nitrogen and hydrogen to ammonia. The process is successfully employed in Germany, where the product is oxidized to nitric acid for munitions manufacture. The technical details of the process are complicated and involved.

It becomes apparent, therefore, that the merits of the three processes are somewhat dissimilar, and they are not all equally adapted to the same conditions. It might be mentioned also that Germany apparently anticipated that a prolonged war would be impossible without drawing on atmospheric nitrogen, inasmuch as Chilean nitrate could be readily barred, while coal-product and organic nitrogen could not meet her war-time needs. At least it is significant that war was declared directly after the successful development of the Haber and cyanamid processes in that country, and it is certain that there it could not have progressed thus far without them.

In the United States the need has been urgent for some time to draw upon atmospheric nitrogen, in order to amplify our present nitrogen supply as well as to insure a relative degree of independence of Chilean nitrate. In 1916 Congress appropriated $20,000,000 to construct a plant for this purpose; but such a plant has not yet materialized, presumably because a new industry can not be established in a sudden and abrupt fashion, but must be smoothly spliced into the general run of industrial development. This attempt is somewhat analogous to the hypothetical case of a wealthy man who, after having neglected the education of his son until his eighteenth year, offers an educational expert $10,000 to accomplish the desired result in a single year. It can not be done. A more stable nitrogen situation will come, not as a result of any single stroke of action but as an outgrowth of a properly nurtured industrial development, whereby both munition and fertilizer needs will be cared for without introducing elements of disastrous competition. The immediate establishment of a great governmental nitrogen fixation plant, granted such a thing were possible, would set up a nonprofit-seeking industry in immediate competition with the coal-product industry. The result would be that the nitrogen gained at one place would be lost at another; but the balance sheet would not remain even, for the whole coal by-product industry would receive a serious if not fatal set-back, with far-reaching results, because of its intricate ramifications into other industries.

This completes the list of sources from which we at present obtain nitrogen on an organized scale. Peat is a nitrogenous substance and is used locally to some extent as a fertilizer. The artificial bacterial inoculation of peat to increase its nitrogen content opens up interesting possibilities, now in process of experimentation; while an even more direct use of nitrogen-fixing bacteria, cultivated in a medium of organic waste, "provides a less visionary project than might appear offhand." On general grounds it seems quite logical to expect that, inasmuch as bacterial action is the method followed by nature in providing the nitrogen compounds required by plants, this process speeded up and controlled by man will furnish the ultimate solution of the fertilizer aspect of the nitrogen problem. If so, this will serve to illustrate again that no problem in this field can be solved at one stroke, but rather requires an evolution of successive solutions, each adapted to the current industrial and economic situation.

Finally, in regard to nitrogen, we have two products, garbage and sewage, now to a large extent wasted, although possessing a distinct fertilizing value. We may look forward to an increasing number of municipal plants employed in rendering these materials suitable for use. But development along this line for proper fruition must be coordinated with all related activities.

POTASSIUM.

The third major plant food is potassium, which, however, like phosphorus and nitrogen, appears in neither fertilizers nor soils in the simple elemental condition, but in the form of various compounds or salts, of which the most important are potassium carbonate, potassium chloride, and potassium sulphate. The term "potash" refers strictly to potassium oxide, used for calculating these compounds to a common basis; but the term is also employed in a loose manner to embrace the potassium salts in general.

Potassium contributes stalk strength and kernel filling to the growing plant. It is present in normal soils partly in the form of a soluble compound, potassium carbonate, produced during the course of soil formation by the chemical decay of complex silicate minerals present in the parent rocks. Where potassium in soluble form is lacking, due to special geological conditions of soil formation, or where it is withdrawn rapidly by continuous crop production, it must be added to the soil from an external source.

Potassium is a very common element. Only seven others are more abundant. There is more potash in the crust of the earth than there is water upon it. The trouble is that, unlike water, potassium compounds are concentrated at only a few places on the globe; and at one of these, the famous Stassfurt deposits in Prussian Saxony, the concentration is in such richness and bulk that this single deposit has for many decades dominated the world in regard to this valuable element. It had to be so, for the problem was not to get potash, but to get cheap potash.

The German deposits were discovered some 60 years ago in connection with deep borings put down in search of rock-salt beds, the region having previously been productive of that more common substance; and as the demand for potash salts grew, developments opened up beds and lenses of practically pure potash minerals of remarkable extent and in such form as to be very readily and cheaply mined. While recent figures are not available as to the tonnage of potash in sight in these deposits, there is no question but that the supply is sufficient to meet the needs of the whole world for a very long period.

The localization of an indispensable mineral deposit within the confines of a single country is in many respects disadvantageous for other countries, at least under the existing order of things. The United States came to a realization of that fact in a general way some years ago, as a result of which both the Agricultural Department and the Geological Survey began a systematic search for domestic sources of supply; but not until the present war cut off entirely the imports of German potash did this country come to a full appreciation of the significance of the situation. As the result, therefore, partly of governmental anticipation (the only conspicuous example of such a course of action in the field of mineral products) and partly of war-inspired activity growing out of soaring potash prices, this country is now producing from a variety of sources a significant but still inadequate supply. A glance at the chart will show the discrepancy between normal consumption and the domestic production for 1916. During the first half of 1917 the home output has practically trebled its rate of production, but on this basis the total supply for the present year will scarcely exceed 12 per cent of the needed amount. While most of the German potash went into fertilizers, still a significant quantity was utilized in many other chemical industries. Some of these have met the issue by substituting in their manufacturing processes sodium salts, of which we have abundant reserves; but that, of course, is impossible in regard to fertilizers.

Practically the only domestic source of potash at the outbreak of the European war was a small recovery made from wood ashes, chiefly in connection with the lumbering industry in Michigan and Wisconsin; but the potentialities in this regard, while important to certain localities, are not great.

The most productive domestic potash enterprise is the recovery of potash salts from some of the alkali lakes of the West, whose waters have been found to be relatively rich in potassium compounds. Jesse Lake in western Nebraska is an interesting example, because its potash is supposed to have been leached from the adjacent plains following extensive forest fires, representing a natural wood-ash extraction. Searles Lake in California has attracted considerable attention because of the reputed tonnage of potash present; its tonnage is undoubtedly great, but a complex assemblage of salts is found, so that its development is proceeding along the lines of effecting a recovery of the several valuable products. Owens Lake, Cal., several lakes in Oregon, and a number of other somewhat similar sources offer potash possibilities, as does also the bitterns or mother-liquor residues in connection with the solar salt plants of Great Salt Lake and the Pacific coast. Considerable drilling exploration has been carried on in favorable geological horizons in Texas, Oklahoma, and other localities carrying strata of arid-climate origin, with the hope of finding potash beds in association, but while results of some little promise have been obtained in a few places, no significant potentialities have been demonstrated.

The mineral alunite, a potassium aluminum sulphate, occurring in deposits of moderate size in Utah, is producing at a small but steady rate, and represents an interesting example of a mineral now in demand which was looked upon a few years ago as worthless.

A potash source which has attracted unusual attention of late, is the kelp or giant sea weed that grows in considerable abundance along the Pacific coast from Lower California to Alaska. This plant has extracted potash from the sea water to such an extent that its ash contains 30 per cent of this material. It would appear that if large areas of this weed could be harvested like a crop and efficiently treated, an effective industry would be the result. The plan has been put into more or less successful operation, at least in the areas of ranker growth in waters south of San Francisco, other products at the same time being saved; but the kelp industry, while it may be made permanent and important, can scarcely be expected to supply more than a very small part of our potash needs.

Perhaps the most significant outgrowth of the efforts toward potash development is the successful application of a method whereby a recovery is made of the dust escaping from the flues of Portland cement plants; this has become a commercial success at more than one locality and opens up the possibility, already under trial, of adding potash rocks or minerals to the normal raw products, so as to increase the by-product potash yield. A potash recovery from the waste dusts and gases from the iron blast furnaces is opening up also as a somewhat similar by-product possibility.

Sundry other sources, such as potash recovery from distillery wastes, wool washings, municipal wastes, ashes from sage brush, banana stalks, and beet-sugar wastes, need not be gone into in detail here, although many of them are producing in a small way. As further development along these lines is in keeping with the assumed principle that the productive utilization of waste products makes for the best interests of the Nation, the furtherance of these by-product activities assumes an importance out of proportion to the actual tonnage of production.

We have finally to examine the possibilities of those leaner but widespread sources of potash, upon which the world must fall back after the exhaustion of richer deposits. Four natural products stand forward in this connection: Feldspar, occurring in scattered and rather small deposits in many parts of the country; leucite, forming a conspicuous component of a rock mass of mountain dimensions in Wyoming; sericite, in extensive beds in Georgia; and greensand, found widespread in the Atlantic Coastal Plain, especially in New Jersey. In each type the potash content is bound up in a very stable form of combination, thus demanding considerable chemical energy for its extraction. Many processes are quite feasible from a laboratory standpoint, but none has met with large-scale commercial success as yet. One of the most promising attempts, already locally successful, makes use of greensand or feldspar, and after the extraction of potash mixes the residue with sand to produce a good grade of brick. This process is not only ingenious in itself, but also illustrates that a raw product should not be looked upon as a mixture of value and waste, but as a combination of useful materials. It therefore serves once more to emphasize the importance of the by-product idea in our industrial development.

The outstanding feature of the potash situation is that the war has brought into existence a varied, loosely connected, and unstable domestic potash industry. What is to become of this industry with the resumption of peace? It will then have to meet the competition of the German potash deposits, which because of their size and workability can deliver potash to any part of the world more cheaply, generally speaking, than can any other source, however near. If it be decided that the American industry, born of war prices, should be stimulated into continued life, looking toward the gradual and normal establishment of American independence in regard to potash as a desirable eventuality, it will be necessary that the Government adopt a definite policy toward this end. Admitted that domestic competition with German potash is economically impossible on equal terms, there would appear to be two methods of making the balance even—either by putting a tariff on the imports from Germany, or else by subsidizing the domestic industrial enterprises to an appropriate degree. The first method would raise the cost of fertilizers to both the manufacturer and the farmer, and would meet with popular disfavor, if properly understood. The cost, in fact, would be too great and fall in the wrong place. The second method could be followed at a moderate cost to the Government; the expense would be distributed and therefore strike no particular class; and the price of food would not thereby be raised. The question would seem to resolve itself, in short, into whether eventual potash independence is worth the price of present governmental subsidy.

CONCLUSIONS.

A survey of the fertilizer situation in the United States brings out a set of striking facts which involve problems in industrial and governmental policy that merit the closest study. We have under consideration a large and complex industry, localized geographically, catering to the most fundamental needs of the Nation; an industry touching other industries at many points, sharing much of its raw material with other industrial demands, requiring raw material in bulk drawn from varied sources widely distributed and embracing at least three continents; imposed upon all this the unparalleled circumstance of a world war, disturbing and cutting off normal trade connections, demanding an enlarged food supply but at the same time withdrawing the physical means for securing it, increasing the demand for fertilizer products yet diminishing the supply. This remarkable chain of facts, starting with two, at least, of the most specialized mineral products in the realm of geological knowledge (Chilean nitrate and German potash), and ending with the war of most far-reaching consequences in all history; involving products (fertilizers) of the deepest importance to mankind as controlling his food supply, as well as other products (sulphuric acid and potash) required almost universally in manufacturing, and a substance (nitrogen) without which war could not proceed a moment—all these have combined to create a situation of unstable equilibrium, the proper adjustment of which can be reached only through a long and careful process of governmental and industrial cooperation.

The shifting public reaction to this situation through the course of its development to the present is interesting and instructive. In 1915, following the outbreak of the war, the focus centered on potash, and a great cry went up when the German shipments waned and the price climbed skyward. For the time being potash held the center of the stage. Then, with increasing demands for explosives, more and more Chilean nitrate was diverted to the manufacture of nitric acid, and the fertilizer industry had to compete the best it could with the imperative calls of war, backed up as they were with the price to pay. This country proceeded to work itself up to a pitch of excitement over the "nitrogen situation," as the realization came that without access to Chile the explosive industry could not be maintained; and finally toward the middle of 1916 a congressional appropriation of $20,000,000 was made to secure nitrogen independence. But the appropriation of money was one thing and the building up of a rational nitrogen situation another; and few understood why money, which purchased everything, could not buy that desired result. Potash had been lost sight of in an atmosphere charged with nitrogen! The next shift of scenes brought sulphuric acid to the foreground; the submarine campaign developed, and it suddenly became apparent that the sulphuric-acid industry was absolutely dependent on shipments of Spanish pyrite. So pyrite assumed the stellar rôle among the galaxy of war minerals. And so the matter stands. All of this, of course, goes to show the unfortunate tendency to regard the potash problem, the nitrogen problem, and the pyrite problem as separate units, whereas, as a matter of fact, they are all parts of a larger fertilizer problem, which in turn is only one phase of a still larger problem embracing our whole industrial life.

It is a basic necessity that we secure an adequate and cheap supply of fertilizers. The responsibility for accomplishing this result is three-fold; resting not only upon the fertilizer industry, but also upon the Government, and likewise upon the people. Each can contribute to this end, both individually and especially through coordinated effort.

The fertilizer industry is awakening to its responsibility. During the past few years, in particular, it has acted on the appreciation that closer cooperation and better understanding between producers and consumers were desirable. An interesting start has already been made toward this end through the work of the Soil Improvement Committee of the National Fertilizer Association, which is carrying on by means of lectures and literature an educational campaign looking toward a more extensive and scientific utilization of fertilizers on the part of the farmer. This is quite different from an advertising campaign merely, and the idea is to be commended. Another problem that will become more urgent as time goes is the one of transportation; for fertilizers are bulk materials and the freight charges not only form an important item in cost, but actually bar off much of the country from more active fertilizer participation. Here is a point of contact between two great industries, touching also governmental policy, with possibilities of adjustment by each; but eventually the fertilizer industry must face squarely the necessity of working actively toward the manufacture of more concentrated products.

The responsibilities of the Government in regard to fertilizers have not yet been fully realized. Those activities which lend themselves to material and disassociated prosecution, such as the manifold activities of the Agricultural Department and corresponding State bureaus and the studies of the Geological Survey on the domestic mineral products, have accomplished results of the highest value along lines of scientific research, practical application, and agricultural education. Such work will continue in increasing amount. But other less material and more subtle problems bring up issues in economic policy which must be met. Their happy solution depends upon a full comprehension of the complexity of the situation, of its intricate ramifications, of the many fields of knowledge involved. Their successful solution will grow out of a policy of *anticipation*, scarcely out of one of lagging accommodation to passing conditions. For the best results, the problems must be solved before they become acute; some of them before they become at all obvious.

The problems now awaiting governmental solution can be only suggested here. One of the more pressing is to adjust the war and peace demands affecting the raw materials of the fertilizer industry so as to avoid the cross-purposes at which those demands are now working. Another is to gradually and normally stimulate the development of domestic sources of supply, not only that a repetition of the present situation will be impossible, but also that a more extensive peace-time production will be the outgrowth. These, of course, depend fundamentally upon the development of a definite governmental policy, clearly expressed, based upon the scientific principles involved, not upon tradition. Such a policy will involve the proper adjustment between industry and government, and will take into consideration the fact that the interests of the Government include those of industry, but, conversely, that it is not the function of industry to look after the interests of the Government. Such a policy, if applied to the fertilizer situation, will solve the current problems as best they may be solved; and will gradually build up an industrial situation that will insure our independence in this respect and prepare us to meet the future exhaustion of the richer sources of our fertilizer supply.

The American public have an interest in this matter. It is their duty to inform themselves in this and other regards, and to increase their perspective so as to press and shape effective action. While the solution of these problems will require the most specialized knowledge obtainable, the comprehension of the situation demands no specialized training. It is the hope of this paper to interpret the situation so that its significant features will stand forth clearly. It is the purpose, in short, of this series of papers to present the salient facts of the American mineral industries, without a popular understanding of which, it is believed, the greatest progress can not be made.

SUMMARY.

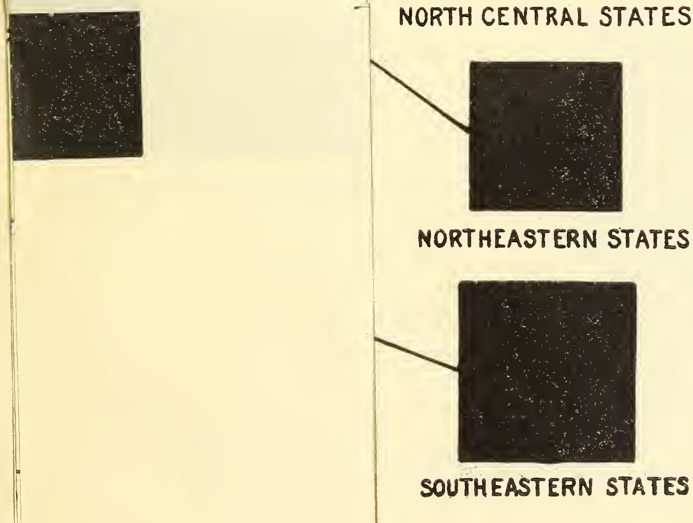
The theories of soil formation and of plant growth are explained in a general way, and it is shown that under prolonged cultivation the soil is exhausted in respect of three of its most important plant foods—phosphorus, nitrogen, and potassium.

The chief source of phosphorus supply is phosphate rock, occurring in present abundance in the United States. As this material must be treated with sulphuric acid to produce fertilizer, its manufacture is closely allied to the sulphuric-acid industry. A critical situation has arisen in this regard, because Spain is the principal source of pryite, from which most of our sulphuric acid is made, and Spanish ore shipments have been endangered and largely cut off as an indirect result of the submarine campaign.

The sources of nitrogen compounds are considered and the strong diversion of Chilean nitrate to explosive manufacture pointed out. The dependence of the United States upon Chile for sodium nitrate and the rising prices of organic nitrogen urge the desirability of an enlarged by-product coal industry and suitable building up of an atmospheric nitrogen industry in this country.

The dependence of this country upon Germany in respect to potash is emphasized and the various war-developed domestic sources of potash described. The assistance that the domestic potash industry merits at the close of the war is discussed.

In conclusion, the point is stressed that the best progress in the field of fertilizer will come through a true coordination of its various parts, both among themselves and together in respect to other industries, as the result of enlightened cooperation between the fertilizer industry, the Government and the people.


NORTH CENTRAL STATES
NORTHEASTERN STATES
SOUTHEASTERN STATES

SMITHSONIAN INSTITUTION – UNITED STATES NATIONAL MUSEUM.

THE FERTILIZER SITUATION IN THE UNITED STATES.

Based on normal times, 1913-1914, but showing principal effects of World-War, 1914-1917.

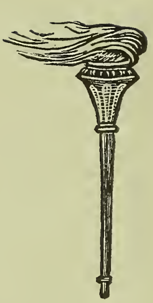
Prepared by the Division of Mineral Technology, U. S. National Museum.

NORMAL CONSUMPTION OF RAW MATERIALS ENTERING LARGELY INTO FERTILIZERS
NITROGEN COMPOUNDS
PHOSPHORUS COMPOUNDS
PYRITE
POTASSIUM COMPOUNDS
SOURCES OF RAW MATERIALS CONSUMED
■ Normal domestic supplies
▩ Normal foreign supplies, endangered by war conditions.
▨ Increase under war conditions
▧ Normal foreign supplies, largely cut off by war conditions
● Potentialities
KEY AREA
■ = 100,000 Tons.
CHILEAN NITRATE (used partly for explosives, etc.)
TANKAGE, COTTONSEED MEAL FISH, GUANO. (nitrate equivalent)
COAL PRODUCT NITROGEN (nitrate equivalent)
CYANAMID (nitrate equivalent)
ATMOSPHERIC other than cyanamid
PEAT
GARBAGE & SEWERAGE
DOMESTIC PHOSPHATE ROCK
TANKAGE, COTTONSEED MEAL, FISH, GUANO (phosphate rock equivalent)
IMPORTED PHOSPHATE ROCK
BASIC SLAG
APATITE
SPANISH PYRITE
DOMESTIC PYRITE
SULPHUR
PYRRHOTITE and other sulphides
SULPHURIC ACID FROM PYRITE
BY-PRODUCT SULPHURIC ACID FROM SMELTER FUMES
About half only of above production used for fertilizers.
GERMAN POTASH 50% potash
WOOD ASHES
SALT & BRINES
ALUNITE
DISTILLERY WASTE
KELP
BY-PRODUCT FROM CEMENT FACTORIES
SILICATES
WOOL WASHINGS
MISC. ORGANIC SOURCES
BY-PRODUCT FROM BLAST FURNACES
NORMAL PRODUCTS
FILLER
Inert material added
ACID PHOSPHATE
COMMERCIAL FERTILIZER
NORMAL DISTRIBUTION.
TONS
WESTERN STATES
SOUTH CENTRAL STATES
NORTH CENTRAL STATES
NORTHEASTERN STATES
SOUTHEASTERN STATES
AREAS
■ = 10,000 sq. mi.
WESTERN STATES
SOUTH CENTRAL STATES
NORTH CENTRAL STATES
NORTHEASTERN STATES
SOUTHEASTERN STATES

EXPLANATION.

This chart is based on data compiled from Mineral Resources of the United States, The Mineral Industry, The American Fertilizer Handbook, Reports of the Department of Commerce, and various special papers. The normal expressions are quantitatively accurate within the limits of error of the scale employed; but the war effects are more generalized, as these are fluctuating and not amenable to rigorous treatment. The attempt has been to simplify in every way possible, so as to give a true picture of the whole situation, unconfused by too many details. Quantities have been expressed in terms of Chilean nitrate (19 per cent NH_3), phosphate rock (32 per cent P_2O_5), and potassium salts carrying 50 per cent potash (K_2O), instead of on a recalculated basis of 100 per cent available plant food, in order that the squares might represent as nearly as possible the relative bulks of the materials actually handled annually by the industry and be mutually comparable. The total productions of materials used only in part for fertilizers are given, as better expressing the situation than an indication of merely the fertilizer share. The decline in normal domestic supplies under war conditions could not feasibly be shown. The increase under war conditions is in general for the year 1916; except where later figures were available, in which instances the fiscal year 1916-17 is represented.

Designed by J. E. Pogue,



SMITHSONIAN INSTITUTION
UNITED STATES NATIONAL MUSEUM
Bulletin 102, Part 3

THE MINERAL INDUSTRIES OF THE UNITED STATES

SULPHUR: AN EXAMPLE OF INDUSTRIAL INDEPENDENCE

BY

JOSEPH E. POGUE

Of the Division of Mineral Technology
United States National Museum

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BULLETIN OF THE UNITED STATES NATIONAL MUSEUM.
Issued November 7, 1917.

SULPHUR: AN EXAMPLE OF INDUSTRIAL INDEPENDENCE.

By Joseph E. Pogue,
Of the Division of Mineral Technology, United States National Museum.

INTRODUCTION.

Sulphur is a chemical element of major importance to man. In addition to its utilization in practically every form of industry, it enters into the make-up of both vegetable and animal tissue and is consequently essential to life itself. The small portion required for the maintenance of life is supplied in sufficient quantity by the soil, but the needs of industry can be met only by recourse to the mining of those parts of the earth's crust in which concentrated deposits of sulphur minerals exist. While the amount of sulphur consumed by a modern nation is small in comparison with the enormous tonnages of iron or coal demanded, its application is nevertheless so varied and fundamental that control of an adequate supply is essential to industrial independence.[1]

Without sulphur the manufacture of commercial rubber would cease and in turn the countless activities dependent upon the use of rubber. Without it a great number of chemical industries would be crippled, involving the loss of hundreds of products catering to the needs of the individual as well as to the machinery of state, such as paper, gunpowder, medicinal preparations, bleaches, dyes, insecticides, and matches. And with no sulphuric acid, the manufacture of commercial fertilizers and of many explosives, not to mention an interminable list of other important products, would be impossible. The provision of an adequate source of sulphur properly administered thus assumes the significance of a national responsibility, in which the individual has the concern of direct personal welfare as well as that dictated by his share in the obligations of state. To contribute to an understanding of how adequately this responsibility for the United States is fulfilled is the actuating motive for this paper. The resulting expression is a review of the existing situation in the light of science without pretense toward an increment to the light itself.

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[1] The importance of industrial independence in respect to mineral products has been clearly demonstrated during the course of the World War when this country was cut off from foreign supplies of such substances as pyrite, manganese, potash, mica, graphite, and others, which were not produced in the United States in sufficient quantities to meet domestic needs.

GENERAL CONSIDERATIONS.

Inorganic nature affords sulphur in three forms of occurrence; namely, in the free or native condition; in combination with one or more metals forming the so-called sulphide minerals; and united with oxygen and certain metals to form the class of minerals known as sulphates. The sulphides include many important ore minerals; indeed, a large part of the world's output of copper, lead, zinc, silver, nickel, antimony, mercury, and other metals is derived from ores which are direct combinations of sulphur with the metal involved. It therefore appears that sulphur has in the past played a part of great importance to the welfare of man as an essential agent in the geological evolution of many important ore deposits. The sulphates, as a class, are of far less importance industrially than the sulphides, though they are widespread in occurrence and bulk, and many of them, such as barite and gypsum, have many useful technical applications. The sulphur industry, as treated in this paper, is confined to a consideration of native sulphur, as free sulphur is not yet won on a commercial scale from either the sulphides or sulphates, owing to the superior cheapness with which it may be obtained from large and easily worked deposits of the native element. The sulphides, it is true, at present yield practically all the sulphuric acid used in this country, obtained either as a by-product in smelting ores of copper, lead, zinc, and silver, or directly by the roasting of pyrite, the commonest of all sulphides, imported largely from Spain; but the sulphuric-acid industry is technically and economically quite distinct from the sulphur industry proper and is appropriately treated under a separate head, though the two industries will probably not always remain estranged.

Sulphur has been known from the earliest times because of its bright yellow color, its conspicuous occurrence in many parts of the world in the neighborhood of volcanoes, and the ability possessed by it of burning with a blue flame to form a pungent gas. Because of this last-named property it came to be regarded by the alchemists of old as the principal of combustion; and this idea is retained in modified form in the symbolical meaning that attaches to brimstone (the Anglo-Saxon used for sulphur) in its frequent use throughout English literature.

Sulphur first sprang into world prominence in the fourteenth century, in consequence of the invention of gunpowder, of which it is an important ingredient. It has held a conspicuous place to the present day by virtue of the increasing use of that explosive, as well as through a growing application in the industrial arts, both in the elemental condition and in the form of various compounds including sulphuric acid.

Before the beginning of the twentieth century, about 95 per cent of the world's supply of sulphur came from extensive deposits in the island of Sicily, where cheap labor and accessible occurrence early led to practically a world monopoly. But the wasteful mining methods employed in most of the Sicilian mines, and the slowness with which these methods were modernized, rendered the industry unfit for the vigorous competition that came as a result of an ingenious and highly efficient method of working large deposits in Louisiana and Texas, first successfully applied in Louisiana in 1903. In consequence, the United States, which once was Sicily's largest customer, not only now receives no sulphur from that source, but has entered the European market as a growing competitor; and the small imports coming to the Pacific coast from Japan need no longer be regarded as significant, now that the Panama Canal affords water transportation from Gulf ports. The position of the United States from 1900 to the present in regard to imports, production, and exports of sulphur is shown graphically in figure 1.

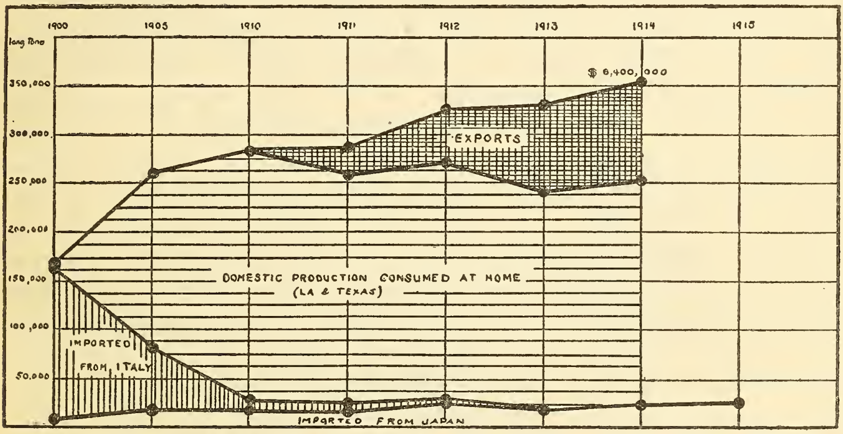

CHART SHOWING THE DEVELOPMENT OF THE SULPHUR INDUSTRY IN THE UNITED STATES FROM 1900 TO 1914. LATER FIGURES ARE NOT AVAILABLE FOR SPECIFIC USE. NOTE THE FALLING OFF OF IMPORTS AND THE DEVELOPMENT OF EXPORTS. THE OUTPUT OF THE TWO GULF DEPOSITS HAS INCREASED APPRECIABLY DURING THE WAR.

Sulphur deposits of potential importance occur in many localities in the United States, including occurrences that have been worked in a small way in Utah, Wyoming, and other western States; but the domestic situation is so dominated by the large reserves along the Gulf coast and especially by the efficiency to which their operation lends itself, that further consideration of the scattered sources would place undue emphasis on their present meaning. The importance of the Gulf sulphur deposits is the result of two factors, mutually important. These are the remarkable and unique manner in which the sulphur occurs, and the novel and highly effective process by which it is obtained without recourse to the costly methods of ordinary mining.

THE GULF COAST DEPOSITS.

The portion of Louisiana and Texas in which sulphur occurs is part of the Gulf Coastal Plain and is geologically a unit. The territory is underlain by stratified rocks of great thickness, virtually horizontal. The even extent of these beds is interrupted here and there by a doming of the strata, producing in many places low surface knolls or mounds. These structural domes, as they are called, first attracted attention in the sixties of the last century in the course of prospecting for oil, when drill holes exposed their structure and content. It was soon discovered that a comparatively large number of these crustal warpings are scattered through a coastal zone extending from Baton Rouge to Galveston and beyond, and that the upbowed beds form a cover for a remarkable assemblage of economic minerals, including petroleum, rock salt, and sulphur.

These domes vary greatly in size, ranging in diameter from a few yards to 1½ miles and extending to depths as great as several thousand feet. When explored by drilling, many of them have been found to consist of a cone-shaped core of solid rock salt, commonly associated with masses of cavernous limestone stained or saturated with petroleum; and almost invariably lenses of gypsum (calcium sulphate) and sulphur are present, the last usually impure or scattered. The upbowing of the strata around each of these occurrences suggests a common origin, namely, a crystallization of these immense bodies of minerals from supersaturated solutions rising from great depths and making room for deposition by the expanding force exerted by growing crystals. The source of these uprising solutions is thought to have been bodies of cooling igneous rocks lying miles below the surface; and the crystallization, once started, is deemed to have had sufficient power to lift bodily the mass of rock lying between the growing nucleus and the surface. Such, at least, is a reasonable explanation of these remarkable geological features; and thus we see that, if these ideas are correct, both the salt and sulphur are ultimately of igneous origin, although the petroleum has probably gathered at a later date in the porous rock surrounding and surmounting the solid core.

The proportions of petroleum, rock salt, and sulphur vary in the different domes, and hence the dominant constituent at any locality is the one for which mining operations are directed. The three, or even two, have in no place been worked in conjunction. The petroleum production from this type of occurrence has been of great importance, especially in the period of 1901 to 1906, when the gushers of the Texas field, especially those at Spindletop, near Beaumont, attracted widespread attention. The salt domes of Louisiana have been worked on a modest scale for several decades, but the centers of the salt industry still remain in Western New York and Michigan. Sulphur has been obtained from only two of the occurrences—one at Sulphur, La., and the other at Bryan Heights, Tex.—but these two produce over 98 per cent of the country's entire output. Other domes probably contain workable masses of sulphur, although in most the sulphur is perhaps too scant to be commercially obtainable.

The occurrence at Sulphur, a small town on the Southern Pacific Railroad, about 15 miles west of Lake Charles, was discovered in 1865 by means of a bore hole put down in search of petroleum. A mass of pure sulphur 100 feet in thickness was encountered beneath several hundred feet of quicksand. Interest immediately attached to this body of sulphur, and during the ensuing 30 years numerous attempts were made to win its content by ordinary shaft mining. All resulted in hopeless failure. At first the main difficulty was to resist the great lateral pressure exerted upon the shaft by the moving water of the quicksand; but after this was sucessfully overcome by putting down a shaft of extraordinary strength, an inrush of poisonous gases from the adjacent sulphur proved fatal to the workmen and indicated that human labor was not feasible within the bed itself.

It became evident that some method of mechanical mining must be devised to meet these conditions. The result was the Frasch process. "This may fairly be described as one of the triumphs of modern technology, and the result of its successful development has been to provide a great industry for the United States, which it did not previously possess, and to remove from Sicily to this country the domination of the conditions regulating the world's supply of sulphur."

The Frasch process was worked out and applied between the years 1891 and 1903 by Herman Frasch, previously engaged in industrial research work in connection with petroleum drilling and refining. In essence, it consists in pumping superheated water through a pipe to the sulphur horizon and lifting by means of compressed air the sulphur thereby melted to the surface, where it is piped to large bins into which it pours in the molten state and cools. The principle is simple enough, but the mechanical difficulties in the way of its practical application were many; among which may be mentioned the tendency of the sulphur to cool and crystallize in transit, the liability of the piping to clog at the bottom, the necessity for avoiding the formation of a water-sulphur emulsion, and the nice adjustment that must be maintained between the pressure of the superheated water and the air-pressure in order to keep the whole system mobile.

The process is carried on by means of a single line of interpenetrating pipes, through the outer of which superheated water is pumped down, while compressed air passes to the bottom through the innermost and forces upward the molten sulphur through the intermediate space. The original well is sunk in much the same manner that an oil well is drilled, and a number of wells are operated at the same time, a particular well being abandoned when the flow falls off and another then opened to take its place. The storage bins accommodate large tonnages in compact form, permitting the laying aside of reserves, and loading is economically effected by means of a mechanical scooper which shovels the brittle mass directly into cars. The process, therefore, is to a large degree mechanical and consequently highly efficient. It marks, indeed, the most efficient of the three major types of mining; underground mining and open-cut, or surface mining, being naturally more costly. While these deposits and this method persist, it would seem that smaller deposits worked by methods less efficient mechanically would have small chance of commercial survival, except in a local way. The economic strength of these deposits is rendered greater by their strategic position in regard to water transportation on the one hand and cheap oil fuel on the other.

The second great sulphur deposit, which together with the one just described, dominates the domestic sulphur industry, is essentially similar in both mode of occurrence and method of mining. It is situated near Bryan Heights, Texas, where the Brazos River enters the Gulf of Mexico, 40 miles southwest of Galveston; a good harbor gives it favorable shipping facilities. The productive portion lies about 1,000 feet beneath the surface, and its development has been more recent than the occurrence at Sulphur just described. The relative output of the two localities can not be given, as these figures have not been publicly divulged.

A visualized idea of the occurrence and technology of the Gulf sulphur deposits may be obtained from plate 1, which is reproduced from a photograph of a model representing a composite of conditions at the two localities described, installed in the Division of Mineral Technology, in the United States National Museum.

CONCLUSION.

In sulphur, to sum up, the United States has a minor mineral resource in which she is not only absolutely independent of the rest of the world, but is able to compete satisfactorily abroad with foreign sources of supply. There are few other mineral industries of which this may be said in equal degree. The United States was enabled to reach this position through the conjunction of a unique geological occurrence, favorably located, with the development of an ingenious technique for making the occurrence cheaply available. It is not generally known how extensive the untouched beds of sulphur are in the two deposits now operating; nor what resources exist in undeveloped and undiscovered occurrences of the same type in the Gulf region. There is, therefore, no available basis of fact for estimating the life of this sulphur supply, though the presumption is that it may be measured in decades, or even in longer units. With the exhaustion of the Gulf fields, the leaner sulphur deposits of the western States will be more actively drawn upon; while processes already under way for recovering sulphur from smelter fumes will undoubtedly be producing important supplies.

A condition has arisen as a result of the World War in connection with the partial cutting off of supplies of Spanish pyrite, from which most of the domestic sulphuric acid is made, which is already affecting to some degree the sulphur situation and may eventually involve a significant increase in production and a diversion of this increment into the manufacture of sulphuric acid. The lack of sufficient pyrite has assumed critical proportions during 1917, and this dearth has directed much effort to the development of the numerous, but small and scattered, deposits of pyrite and related sulphides in the Eastern States. But the development of new mineral deposits is ever a slow matter, even under stress, and in this instance the factor of uncertainty as to the duration of the war and especially in regard to the difficulties that these new-born enterprises will have to meet when thrown into active competition with the Spanish deposits at the close of the war, is not a favorable accelerator to private industrial initiative. Should we be completely cut off from Spanish shipments in the near future, the Gulf sulphur deposits would of necessity have to be drawn upon to tide over the sulphuric acid crisis thus created. As a matter of fact, these deposits have in the past few months been contributing some sulphur to sulphuric acid plants, but an important application in this respect has been heretofore barred by a number of factors, such as the necessity for a slight change in manufacturing technique, the purity and relatively high price of the Gulf sulphur, and the general uncertainty as to the extent of the deposits which has raised the question of the advisability of drawing upon limited reserves of a very pure product for a crude and bulk application. In regard to the last point, it may be said that sufficient data are not in hand for settling this matter, and it would therefore appear that the need is already urgent for a field determination of the sulphur reserves in the whole Gulf region with a view to defining the proper aid that these deposits should render to our sulphuric acid needs, not only during the war but afterwards as well.

SUMMARY.

Two sulphur deposits near the Gulf coast in Louisiana and Texas, worked by an ingenious and efficient mechanical process, not only are supplying practically all of the crude sulphur in this country, but their development has shifted the world's largest sulphur industry from Sicily to the United States. The geological occurrence and method of working the Gulf deposits by means of the Frasch process are described in nontechnical language. The bearing of these deposits on the sulphuric acid situation is discussed and the need pointed out for a determination of the sulphur resources present in the whole Gulf region, with a view to defining a proper adjustment between the needs of the sulphur industry and the sulphuric acid industry.

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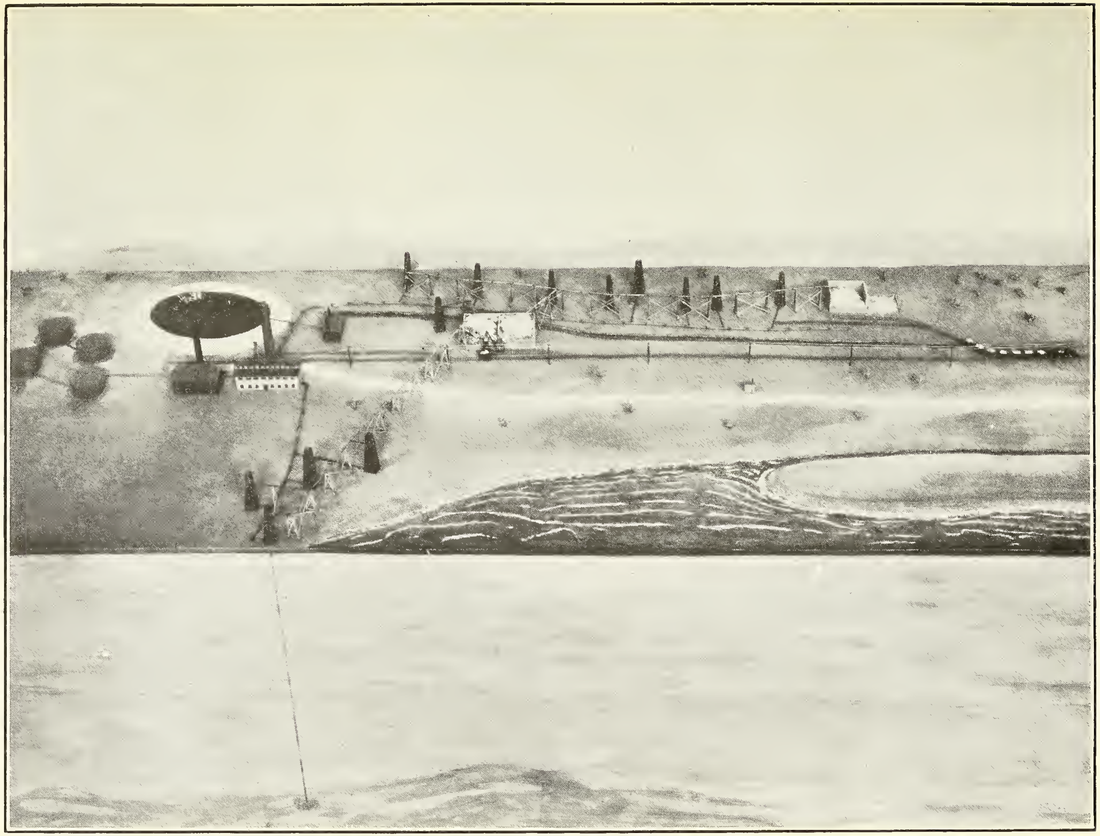
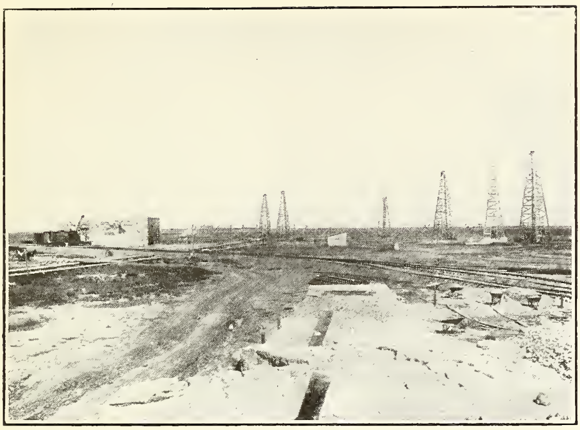
BIRD'S-EYE VIEW OF THE OCCURRENCE AND MINING OF SULPHUR IN THE GULF COAST REGION.

Photograph of a model in the Division of Mineral Technology, United States National Museum.

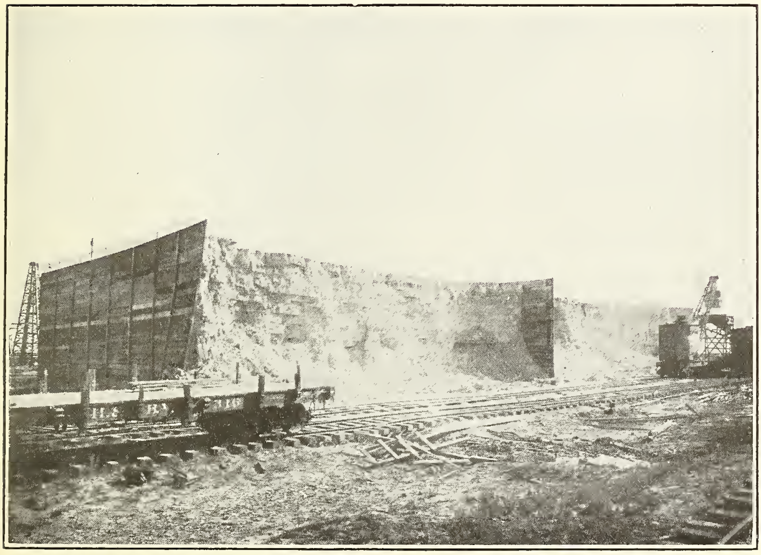


Nearer View Showing in Greater Detail the Frasch Process of Mining Sulphur in the Gulf Coast Region.

Photograph of part of model reproduced on Plate 1.



View, from Actual Photograph, of Sulphur Mining in the Gulf Coast Region, Showing Wells by Means of which the Molten Sulphur is Raised to the Surface from the Productive Beds Below.



View of Sulphur Mining in Gulf Coast Region, Showing Storage Bin in which the Molten Sulphur is Allowed to Cool, and Method of Mechanical Loading on Freight Cars.

SMITHSONIAN INSTITUTION
UNITED STATES NATIONAL MUSEUM
Bulletin 102, Part 4

THE MINERAL INDUSTRIES OF THE UNITED STATES

COAL: THE RESOURCE AND ITS FULL UTILIZATION

BY

CHESTER G. GILBERT
AND
JOSEPH E. POGUE

Of the Division of Mineral Technologyy
United States National Museum

WASHINGTON
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1918

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FOREWORD.

Mineral resources are coming more and more into prominence as the basis upon which modern advance is built. Their adequate development is a matter of the first importance, and public opinion will be called upon in increasing measure to shape the course of advance in this fundamental field. As the general subject is not one of popular experience, this series of papers is under preparation for the purpose of interpreting in nontechnical language the significant aspects of each resource of mineral origin, in anticipation of a growing demand for concise summations of technical knowledge in a form adapted to current use.

The sources of energy underlie the employment of all raw material, and this paper on coal, together with those to follow on water-power and oil, aim to present a constructive analysis of the fuel situation in the United States.

COAL: THE RESOURCE AND ITS FULL UTILIZATION.

By Chester G. Gilbert and Joseph E. Pogue.

Of the Division of Mineral Technology, United States National Museum.

In spite of ample supplies in the ground, coal inadequately meets its obligations because of the competitive manner in which it is mined, the unnecessary extent to which it is transported, and the improper way in which it is used. The first has caused tremendous waste, the results of which will be felt heavily in the near future; the second has caused a coal shortage in the present period of stress and promises a repetition at every coming period of sudden industrial expansion; the third has imposed an excessive burden of cost upon the public. To prevent waste, to circumvent shortage, and to lower cost, changes in our system of coal economics are necessary. These changes must be determined by coal itself—by the nature of its geographic distribution, geologic occurrence, mining technology, and chemical composition. It is the purpose of this paper to draw from the considerations enumerated—from an analysis of the resource—an expression of the directions which these changes should take. As the most significant deficiencies are inherent in the utilization of coal, the subject will be approached from that point of view.

I.

The United States in 1917 produced in round numbers 640 million tons of coal. About one-seventh of this, or 90 million tons, was anthracite, while the rest was bituminous coal of various grades. The anthracite came from a small area of less than 500 square miles in Pennsylvania; the bituminous supply, from 30 States, with Pennsylvania, West Virginia, Illinois, and Ohio contributing about three-fourths of the total. Anthracite is hard coal, of uniformly high heating value, and burns without smoke; it is relatively costly to mine and prepare; it is regarded as the ideal fuel for the American home. Bituminous coal is soft coal, of slightly lower thermal value in the raw state as compared with anthracite,[1] and burns with the production of black smoke; it is cheaper to mine and to prepare than anthracite; it constitutes the dominant fuel dependency of American industry and commerce, and is used in American homes that can not afford anthracite. Vast quantities of coal lower in grade than bituminous, such as lignite and peat,[1] occur in many parts of the United States, but these as yet are practically untouched.

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[1] True in the average only; the highest-rank bituminous coal has a heating value greater than that of anthracite.

Coal as now used fulfills three distinct and unrelated functions. It furnishes industrial power, material for the manufacture of coal products, and domestic heat.[2] About two-thirds of the coal consumed in the United States goes into the production of power which is divided almost equally between the industries and the transportation systems; about one-sixth is used as a raw material for making substances employed industrially, such as metallurgical coke, upon which the iron industry depends, and gas, nitrogen compounds, benzol,[3] tar, and coal-tar products. One-sixth approximately is employed for heating homes and other buildings. It will be observed, then, that the combined industrial requirements outweigh the needs of the home five to one.

This threefold function of coal involves the element of competition, which is latent in normal times, but becomes effective in periods of stress. War conditions in America have lately developed in acute form the inevitable consequence of this competitive tendency, a shortage of fuel for domestic heating.[4] Industrial users of coal are strong and preponderant; they can meet a growing cost by passing it on to the consuming public in the form of higher prices; and in cases of shortage they are normally given precedence in distribution. Domestic users of coal, on the contrary, are scattered and weak; in general they must accept what is left after the wants of industry are satisfied. The home, therefore, is forced to pay a price developed by the industrial demand, or else, if the price be artificially fixed, suffer more than its relative share of the shortage which the expanded demands of industry create. This condition is not peculiar to the present situation, though never before, of course, so gravely manifest; it is inherent in our present system of fuel utilization, which if unchanged may be expected to display a repetition during every future period of industrial quickening. Moreover, the growth of industrialism, by increasing the industrial consumption in respect to the domestic, will serve to make the danger progressively more serious.

The competitive tendency that now obtains between the three main uses of coal is not justifiable on the basis of the character of coal itself. On the contrary, these functions, at present antagonistic, are fundamentally complementary, and they can be made so in practice to their common advantage, in respect both to yielding cheaper products to all interests as well as to imparting a stability and elasticity to the supply that will better enable it to weather periods of stress. In the ideal utilization of coal, the domestic and products uses will be completely complementary, while the power use will supplement the other two. Each will benefit from the others, and one can not be adequately developed without the participation of the other two. The means whereby this advantageous cooperation may be effected are feasible and within the reach of an immediate start toward realization.

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[1] Peat is not strictly a coal in the commercial sense, though it represents one of the first stages in coal formation.

[2] Coal, of course, is used for other specific purposes, but these are of secondary importance.

[3] Benzol is the light oil often included in the term coal-tar.

[4] This shortage, indeed, has been so great as to extend into industry also.

Even with the utmost accomplishment in the direction of full, coordinated utilization of coal, however, there will still remain the dominant claim of power generation, involving by its size an undue tax upon the transportation facilities of the country. This persisting characteristic of present usage, with all its potency for evil consequences, can be alleviated through the development of a power resource more mobile than coal, which will relieve the railroads of part of their coal-hauling responsibility. Such a resource is at hand in the form of hydroelectric power, as yet hardly touched in this country; and the bearing upon the coal situation, and especially upon its transportation aspects, that a proper utilization of this source of power would have, is the subject of a separate paper, to follow this.[1] The adequate development of water-power would not only relieve an unnecessary reliance upon our transportation systems, but it would also reduce the power use of coal to a portion more amenable to smooth coordination with the parts employed in the coal-products industries and the home.

The point of logical attack upon the coal problem, then, centers in the home, for here lies the greatest weakness in the present system of coal utilization. It is in the home that conditions are the most discomforting in times of stress, that trouble, whether it be of high price or actual shortage, has the least chance of remedy by industrial enterprise. The problem, too, finds its closest contact with the individual in the affairs of everyday life; and its complexities may be reduced to their simplest expression in terms of this point of view. But it should be clear that although the line of advance may start with changes that benefit the individual user of coal, the course of progress brings no less advantage to the fields of industry. The whole matter, however, concerns the individual directly and foremost; he will be the gainer or loser according to whether or not he sees fit to interest himself in the means for effecting the progress not merely needed, but absolutely essential, to the well-being of the immediate future.

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[1] Power: Its significance and needs. Bull. 102, Pt. 5, U. S. National Museum (in preparation). In this paper it will be shown that the transportation of the portion of coal used for power generation, engaging as it does one-third of the freight capacity of the country, involves an unsound proportion that must be lessened by taking advantage of the undeveloped water-power resources of the country. This will give a source of power without substance and independent of the ordinary channels of transportation.

Approaching the coal problem from the point of view of the domestic user, we find that the homes of the country are insistent upon anthracite, in so far as its use is not precluded by expense or excessive distance from the point of production in Pennsylvania. Thus the entire northeastern part of the country is entirely, and contiguous territory as far west as St. Paul and as far south as Atlanta, is partly, dependent upon what is popularly termed hard coal. As is well known, this is due to the twofold fact that anthracite is clean, both in handling and in its smokeless combustion, and its heating effect is uniform and high. It is needless to add that the dependency developed because a coal resource of this type was present in a populous and accessible part of the country.

But anthracite is a luxury. It combines refinements of quality with limitations of supply—the characteristics of every luxury. Its cost of production is approximately twice that of bituminous coal;[1] it emanates from one region only, a district of heavy freights; it has no capability toward yielding by-products to modify its cost; besides, a big fraction of the available supply is already exhausted. Its domestic use may be continued as a luxury, but anthracite must be dismissed as not equal, or adapted, to the task of supplying the American home.

The home, therefore, independently of its wishes in the matter, must turn to bituminous coal for its fuel dependency. There is no alternative. Already this has happened to a partial extent; war conditions are accelerating the change; the future demands it more completely. The advantages of bituminous coal are well known—its relative cheapness, its wide distribution, its ample reserves,[2] the possibility of improved utilization. But there is one grave objection to the use of bituminous coal—its dirtiness. This is a valid objection. Burned in the raw condition, it gives off dense, black smoke which dirties the home, pollutes the atmosphere, and becomes the implacable enemy of civic betterment as well as a menace to the health of the city dweller. Such a result can not be countenanced.[3] It so happens, however, that smoke represents the most concentrated value in bituminous coal. If we can extract this value and use it toward reducing the cost of fuel, at the same time making a smokeless product for heating use, the sole objection will be turned into an advantage, and the domestic fuel problem will be solved.

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[1] Responsible for this is a complicated geological occurrence, involving folded strata, depth, water, and association with thin seams of slate, as contrasted with the average flat, close-to-the-surface beds of bituminous coal.

[2] Less than 1 per cent of the bituminous coal of the country has been used.

[3] Furnaces which consume the smoke are in use, but they have made no impression on the general situation; they can not meet universal acceptance, because they throw the smoke on the debit side of the balance sheet, instead of into its true position, the credit side.

In 1915, before the price of coal was enhanced by war conditions, the average value of bituminous coal at the mine was $1.13 a ton. By way of contrast, we may tabulate the latent values contained in this quantity of raw coal, giving the figures in round numbers and basing the calculations on prices prevailing in 1915.

Balance sheet showing contrast between value of 1 ton of bituminous coal at mine and value of products which it contains, based on conditions prevailing in 1915. The contrast is greater to-day.

	Value at mine, 1915.	Quantity.	Value at point of production, 1915.
1 ton (2,000 pounds) bituminous coal contains	$1.13	1,500 pounds smokeless fuel	[1] $5.00
		10,000 cubic feet gas, at 90 cents per 1,000	[2] 9.00
		22 pounds ammonium sulphate, at 2.8 cents	.61
		2½ gallons benzol, at 30 cents	[3] .75
		9 gallons tar, at 2.6 cents	[3] .23
Total	[4] 1.13		15.59

[1] Figure based upon approximate selling price of anthracite.
[2] Figure based upon average price of city gas.
[3] These figures would be much higher if an adequate coal-products industry were in existence.
[4] This figure shows clearly that lowering the cost of production can not be expected to lower the price of coal. Even if the cost of production were eliminated, the price of coal would merely be a dollar less.

Obviously, there should be a way for the home to get its fuel more cheaply than it has, when a ton of coal worth $1 at the mine contains about $14 worth of commodities useful to society.

One answer to how these values may be got in full from coal lies in the development of artificial anthracite. The accomplishment depends merely upon the establishment of a process which will isolate the solid-fuel portion of bituminous coal in the form of a substance equivalent to anthracite, and produce from the remainder a number of products whose value could be made to more than carry the expense of the operation. Nature has pointed the way with natural anthracite, which was originally bituminous coal, but has subsequently, under the stress of geological evolution, lost its volatile portions, forced out by the action of pressure and heat. It is merely a matter of accomplishing a similar result by artificial means, but with the important advantage that while nature dissipated the volatile constituents and produced only one end product, man could catch these values and turn them to his advantage. There are no insuperable difficulties in the way of such an accomplishment. Several processes capable of this attainment are already in course of development, although comparatively little organized research has been directed to the problem. An intensive attack, such as the importance of the matter deserves, would unquestionably yield an entirely satisfactory procedure. The problem, in reality, is rather one of economics than of technology. When the need of artificial anthracite is generally appreciated, a suitable process for its manufacture will be forthcoming.[1]

Granted the necessity for a smokeless fuel other than anthracite and recognizing that it is chemically feasible to make such a product from bituminous coal, we may examine the existing economic practice that bears on this matter, with a view to ascertaining at what place, if any, a process as outlined above may be introduced and placed on a working commercial basis.

II.

We naturally turn first to the coke industry, for here the greatest progress in coal utilization has been attained, and besides coke has already been used to a limited extent for domestic heating. The coke industry consumes nearly one-sixth of our bituminous coal, and has as its immediate purpose the production of coke, a substance required by the iron industry, which absorbs most of the output.[2]

Coke is made by heating certain classes of bituminous coal at high temperatures, with the production of a hard, porous residue, composed essentially of carbon.[3] Two methods of manufacture are in general commercial use. One employs beehive ovens, so called from the shape of early types; the other makes use of retort ovens, which are usually long and narrow and assembled in batteries. The latter are also appropriately termed by-product ovens.

The beehive oven delivers a product well suited to metallurgical use, but the process is objectionable because of the waste involved. It not only fails to yield the maximum of coke, but it effects no recovery of other valuable constituents. The products lost represent a measurable waste in terms of dollars, but they carry greater significance as being the raw materials upon which could be built an adequate manufacture of fertilizers, dyes, drugs, and explosives. It is a strange anomaly that the beehive oven has been made necessary by American economic policy.

The by-product oven receives raw bituminous coal and subjects it to destructive distillation. This process consumes none of the coal, but breaks it up into five components—coke, gas, ammonia, benzol, and tar—of which coke is the main product, while the other four are called by-products. About half of the gas produced is used to supply the heat essential to the operation; the by-products are partly or wholly recovered according to the details of the practice. Where the by-products are wholly recovered, no part of the coal is wasted. In round numbers, 1 ton of bituminous coal yields 1,440 pounds of coke, 10,000 cubic feet of gas, 22 pounds of ammonium sulphate,[1] 2½ gallons of crude benzol, and 9 gallons of tar.[2] Half of the gas is available for use as fuel or in lighting; the ammonium sulphate is a valuable fertilizer; benzol is an excellent motor fuel, a substitute for gasoline; tar is a waterproofing material used for making roofing and for dressing roads.

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[1] When a specific industry is in need of a process to attain a certain end, it goes ahead and perfects the process. No individual industry is in need of artificial anthracite, but public interest demands it. The responsibility is obvious; it falls upon the public.

[2] From 1 to 1¾ tons of coke go into the production of 1 ton of iron, so that the coke industry is essential to the iron industry. Coke also enters into a number of other metallurgical processes.

[3] Much of the bituminous coal in the United States is not suited for the manufacture of coke because it yields a product not physically adapted to metallurgical use.

These four first-products have an unlimited field of usefulness as such. In addition, three of them represent raw materials upon which important fields of present industry are dependent and upon which, if bountifully supplied, new industrial activities of far-reaching consequences can be reared. The ammonia, recovered as such, instead of in the form of ammonium sulphate, forms the basis of modern refrigeration and is used for making explosives and chemicals. Benzol is a mixture of substances, including the deadly toluol, which can be made to yield explosives, dyes, drugs, medicines, solvents, photographic developers, and other chemicals. Tar, likewise, yields a 10 per cent fraction which may be turned into explosives, disinfectants, dyes, drugs, and other products. Benzol and tar, in short, are the basis of the coal-tar industry, inadequately developed as yet in America—an industry which Germany has intensively cultivated to an advantage now well known.

The by-product oven is complicated and costly to install[3] and to operate. Like the beehive oven, its prime purpose is to deliver coke, but it can compete with the beehive only when the by-products can be disposed of with sufficient advantage to cover the greater expense of the by-product practice and contribute a margin of incentive. The development of by-product coking in the United States has been slow, considering the social and national importance of the possibilities inherent in this activity. At the beginning of 1918, the beehive oven still turned out over half of the coke produced, although war conditions and war demands have given a strong impetus to by-product coke development.

The reasons for the lagging growth of by-product coking in America are clear and specific. There has not been a sufficient demand for all five of the products, due to inadequate industrial utilization of gas and the practical lack of a coal-tar industry.[4] Our economic adjustment gave a stable demand for only two of the products, coke and ammonia. The gas had a varying value from a product representing the chief source of revenue in some instances down to one giving returns too small to justify its storage.[1] The benzol, a few years back, was not even recovered, so lacking was any demand for it.[2] The tar, like the gas, had a considerable though low range in value, but until a few years ago it was scarcely profitable to extract it.

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[1] The solid form in which much of the ammonia is recovered.

[2] These figures are approximate. They vary with practice and grade of coal.

[3] The cost of constructing a modern by-product coke oven plant of minimum commercial size in normal times would be nearly a million dollars; under present conditions, more than twice that amount.

[4] Also the apparent abundance of gasoline put no demand upon benzol as a motor fuel, contrary to the experience of European countries.

The consequences of inadequate coal-products development in the United States have been serious, in some respects critical. Here falls entire responsibility for recent shortages in explosives of certain types, as well as in dyestuffs, and a variety of drugs and chemicals; partial responsibility for the high cost and inadequate supply of nitrogen compounds and gasoline; and even a little of the blame for the transportation congestion of 1917–18, which industrial coal-gas utilization could have alleviated in some measure. These considerations are apart from wasted materials and wasted opportunities. The coal-products situation, indeed, represents one of the most complex, subtle, and important problems in the whole field of industry to-day; and this is true not only in respect to present conditions, but also as regards the trend of future industrial growth to a degree difficult of full appreciation. The failure of Great Britain to sense its importance before the outbreak of the European war came desperately near causing her defeat during the first few months of hostilities through a lack of toluol; the situation was only saved by the happy chance that the British gas industry was developed with by-product recovery, and by straining met the emergency. A similar failure on the part of the United States is responsible for some of our present embarrassments. A failure to remedy the situation will place this country at an unfortunate disadvantage in the future. It seems remarkable that a single, partly developed unit of industry can have such a vital and far-reaching bearing on the well-being of the entire nation, but such is unequivocally true of coal products. That fact can not be expressed too plainly or in terms too strong.

To build a proper coal-products industry, even within the limits set by the coke needs of the iron industry, will require the establishment of a steady demand for the four by-products—gas, ammonia, benzol, tar—which will give them a commercial value in keeping with their real worth. This, in turn, will depend upon an enlarged utilization of gas for fuel purposes, and the growth of a substantial coal-tar industry that to the certain values of the primary products will add indefinite constructive possibilities of increased values in a field already advanced to the point where warfare, textiles, and chemical manufacture are utterly dependent upon it. The whole accomplishment waits upon a constructive economic policy which recognizes in true perspective the pivotal importance of coal products.

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[1] It is significant that in 1915 the average cost of city gas was 91 cents per 1,000 cubic feet, while the average cost of gas from by-product coke ovens was 10 cents.

[2] And benzol contains toluol, upon an adequate supply of which modern warfare is absolutely dependent.

The significance of the coal-products field and the need for its adequate expansion has been dwelt upon at length, because this matter concerns not merely the portion of bituminous coal made into coke, but bears with peculiar meaning upon the utilization of the much larger portion consumed as fuel.

Having examined the coke industry and observed its main purpose, the production of metallurgical coke, and the incidental recovery of by-products on the part of nearly half of the activity, we may ask if this industry can not extend its scope so as to produce a surplus of coke which may be applied to fuel use. The answer is in the negative. Coke, being designed for another purpose, is not a satisfactory fuel. While smokeless in combustion, its cellular structure gives it an intensity of combustion and susceptibility to chill that renders its control troublesome. Even a radical change in furnace design can not be expected to overcome this difficulty. Moreover, the coke industry is centralized, subject to marked fluctuations according to the demand for iron, and has not yet succeeded in modernizing more than half of its practice. Besides, its by-product manufacture is complicated and costly. Metallurgical coke, then, must be dismissed as an impracticable general-service fuel. The by-product coking practice, however, illustrates the principle of full coal-value utilization and therefore points the way toward progress in respect to fuel coal. Modified by-product plants, simpler than by-product coke ovens, producing a non-cellular carbonized residue and located near the points of utilization, represent the lesson to be drawn from the coke industry.

III.

We may turn next to the gas industry to ascertain if this activity is capable of adaptation so as to contribute an adequate smokeless fuel for domestic and power consumption. This industry consists of a great number of separate plants, distributed, one or more each, among the cities of the country.[1] In the aggregate these plants consume about 1 per cent of the annual coal production of the country. Their prime purpose is to manufacture gas, and this they do without adequate regard to the complete recovery of by-products, although many plants effect a partial recovery of ammonia and tar, and some gas-house coke is put upon the market. Apart from the oil-gas plants on the Pacific coast, in which petroleum is used because of its relative cheapness in that region, the gas industry of the country employs coal as its raw material.

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[1] There are over 900 artificial- gas plants in the United States, exclusive of by-product coke ovens.

Three types of gas made from coal are in general use—coal gas, carbureted water-gas, and mixed gas. Coal gas is distilled from bituminous coal by heating the latter in retorts. Carbureted water-gas is produced as a result of the action of steam upon coke or anthracite, the nonilluminating water-gas thus produced being then "carbureted," or enriched, by the addition of a gas of high thermal and illuminating power made from oil. Mixed gas is a mixture of coal-gas and carbureted water-gas and is supplied in many cities in the United States, the coke from the coal-gas production furnishing the basis of the water-gas manufacture.[1]

The gas companies are by nature and in fact public utilities. They manufacture a necessity which does not lend itself to competition. They are private enterprises under municipal control, which is largely directed, however, to price restrictions, and is not constructive in the way of compelling advances in technical procedure. With some exceptions, the average municipal gas plant is a small and antiquated organization, both in practice and in vision, far behind present possibilities of manufacture and application.[2] In some cities in the United States, the gas companies are in the nature of large public-service corporations, which have made considerable advance in gas production, but nowhere is there full by-product recovery and the price of city gas is uniformly high.

Although the municipal gas plant now meets rather inadequately only a small share of the fuel needs of the community which it serves, it represents an established activity which can be converted into an organization that will supply all the fuel, whether gaseous or solid, that the community consumes. The transformation may retain the gas mains and much of the other equipment of the present type of plant, but in the place of the present procedure with relative neglect of by-product recovery will be substituted a by-product system of coal distillation, producing artificial anthracite, gas, ammonia, benzol, and tar. This will mean in each city a centralized purchase and consumption of raw coal, and a centralized distribution of products. The output will be limited at first at least, by the demand for solid fuel. A production of ample solid fuel will give an excess of gas over that now produced, which will call for an expansion in the use of gas, both in the home and in industry. Such expansion will come as a result of cheaper gas, incidental to the proposed plan of production, together with improvements in methods of utilization; and this very expansion will cut down the use of solid fuel and thereby hasten the adjustment. The three remaining first-products, ammonia, benzol, and tar, as already pointed out, have an unlimited field of usefulness as such, even within the municipality;[1] and by shipment will contribute a supply of raw material to the needs of the coal-products industry, thus permitting and inducing this important field of endeavor to advance beyond the limits now imposed upon it by the coke industry.[2]

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[1] In many cities the gas plant is hampered by the imposition of a standard based on candle-power. This is a survival of the flat-flame use of gas, and now that the incandescent mantle makes heat in the flame and not artificial enrichment in the gas the true object to be sought, a calorifice standard should supersede altogether an illuminating one.

[2] In Great Britain the gas industry is far in advance of that in the United States; allusion has already been made to the important rôle it has been able to play in that country by supplying toluol for explosive manufacture. It should be emphasized that the gas industry in the United States has been impeded by restrictions imposed by economic conditions and by the type of public control affecting its affairs and in consequence is by no means wholly responsible for such delinquencies as exist.

The objection may be advanced that artificial anthracite has not been perfected and placed on a commercial basis, and until such time the utilization as outlined above must wait. It is indeed true that such a process is not worked out in detail and ready to be fitted into the present gas industry, but a similar condition has been a stage in the development of practically every technological process and the recognition of the demand has created the means for its accomplishment. But even granting the objection as valid, we find that the production of artificial anthracite is only one of two solutions to the problem of developing an adequate smokeless fuel from bituminous coal. The prime idea is to separate the heat- or energy-producing portion of the coal from the constituents valuable as commodities, and dispose of the two groups to their mutual advantage. Hence if we convert the energy component entirely into gas and recover the by-products, we may accomplish our purpose without calling into service a single procedure which is not already in successful practice in other fields of industry. The municipal gas plant affords, in the second instance also, the logical point of attachment for the development. Only, in this event, in the place of artificial anthracite and gas, plus ammonia, benzol, and tar, the output would be gas entirely, with a similar production of ammonia, benzol, and tar.

The twofold possibility of advance in coal utilization brings up the relative advantage of a solid, smokeless fuel versus a gaseous fuel. Their applicability for domestic use may be examined first. Solid fuel, such as artificial anthracite, requires no change in present types of furnaces and grates; is applicable to suburban and out-lying districts not served, or servable, by pipes; and will always be in demand for open fires. Gaseous fuel, on the other hand, eliminates the factors of storage and haulage, reduces dirt, and through the automatic temperature control of gas-fired furnaces nullifies the conspicuous losses growing out of ignorance and waste in connection with present hand-firing. For industrial purposes, gas offers conspicuous advantages, as evidenced by the varied industrial use of natural gas in all regions where abundance of supply creates a favorable price.

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[1] Ammonia as a fertilizer, benzol as a motor fuel, and tar as a road dressing.

[2] It is not beyond the bounds of reason to foresee a condition whereby a householder, in the place of his ton of anthracite which he now welcomes for $11, will receive a ton of smokeless coal without slate, a month's supply of cooking gas, 40 miles of motor fuel, enough fertilizer to start a small garden, and tar sufficient to allay the dust in front of his house—all for far less money than he now pays for inferior coal. This may appear a fanciful picture, but coal has precisely this possibility within itself.

In general, gaseous fuel is bound to increase in importance as compared to solid fuel, especially in the industries. While solid fuel lends itself to conversion into power only through the agency of the wasteful steam engine, gas may be used in the internal combustion engine, which for the same equivalent consumption delivers in general over twice the power; while for purposes of producing heat, gas presents an ease of control and a mobility of application that place it beyond comparison. Moreover, and more important than all, solid fuel has already reached a far fuller measure of development than has gas, whose utilization is still in a relatively undeveloped state. Improvements in the internal combustion engine, the utilization of gas under pressure, and the application of the so-called surface method of combustion offer lines of advance that will add a growing weight of superiority to the use of gas.

For domestic purposes, however, the advantages of solid and gaseous fuel are somewhat complementary, rather than opposing, so that advances toward perfecting the two types of fuel may well be simultaneous. The successful operation of an artificial anthracite plant will demand increased utilization of gas, involving the employment of the latest advances in its application; while the operation of an enlarged municipal gas-plant, with adequate by-product recovery, however effective in the way of economical gas supply, can not be expected to replace fully, at least for some time, the need for a smokeless solid fuel. In either event, therefore, the tendency will lead toward an increased rôle for fuel gas, a trend in line with the inevitable necessity for a more mobile and more efficient source of heat and power than is afforded by solid carbon.[1]

The successful instigation and operation of either of the two plans proposed will depend upon public initiative and stimulus. Neither plan may be expected to come into action under the influence of private industrial enterprise; a private organization would have no means of getting adequate returns upon the development expenditure since the benefits contemplated would accrue alike to all industrial activities as well as to the public. The first move, therefore, devolves upon the public; or at least, upon organizations representative of the public interest. The accomplishment, however, will call for a more effective administration of public utilities than has obtained in American cities in the past, and this will come only after full public realization that technical affairs must be directed by technical knowledge.

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[1] It is scarcely necessary to point out that both solid and gaseous fuel are adapted to the generation of electricity.

IV.

Although the whole coal problem has been approached from the point of view of effecting advances in utilization that will tend primarily to the advantage of the householder, the plans outlined may be extended to meet an appreciable portion of the requirements of industry; in fact, their success even requires a certain coordination with the fuel needs of industrial activities. As already pointed out, development of artificial anthracite will give an excess of gas over present domestic wants which must be consumed, in part, in power generation now dependent upon raw coal. Artificial anthracite itself would be suitable for steam raising and therefore offer to industry the same advantages that it holds for the home, including the possibility, if fully used, of making our cities and railways completely smokeless. The adequate development of artificial anthracite, in coordination with a large coal-products industry, may be expected to create a competitor for raw coal that would gradually put it out of use; for there is no insuperable reason why the fuel portion of coal should not be widely available at less cost than raw coal. The alternate plan of complete gasification of coal, with by-product recovery as carried out in municipal public utility plants, would of course offer abundant gas for industrial use in manufacturing centers, enabling the wastful steam engines to be replaced by the more efficient internal combustion engine; while at the mine a similar procedure, under private control, could be made to supply gas for nearby distribution or convertible at once into electrical energy, susceptible of effective transmission within a radius of two hundred miles. Electrical energy, indeed, is now being generated at the mine mouth in some of the more populous coal-mining regions, with the difference that the coal is not gasified but is used in the raw state under steam boilers; offering the objection, therefore, of inadequate recovery of energy and commodity values.

In Europe, with the necessity for economies in fuel consumption, far greater advances in the utilization of coal have been attained than in the United States. And these advances, it may be observed, are such as to lend the encouragement of successful experience to the changes in coal utilization demanded by the needs of our own situation. The status of the British gas industry has already been adverted to as higher than that of the corresponding activity in the United States; while the by-product coaking of coal, as is well known, has been carried further in Germany than elsewhere, resulting in the strong position attained by that country in the manufacture of dyestuffs, chemicals, and explosives. Noteworthy progress abroad centers also around the development and use of producer gas, the briquetting of low-grade coals, and to a limited degree around the manufacture of domestic "coke."

Producer gas is the result of the complete gasification of coal under the action of a mixture of air and steam.[1] Both high-grade and low-grade coals may be employed in its manufacture and the gas may be produced with or without the recovery of the by-products, ammonia, benzol, and tar. Most of the foreign by-products producer-plants, however, at least before the war, made adequate recovery of the ammonia only. The producer principle is not only successfully applied to central plants manufacturing gas for transmission as such or for the generation of electricity; but it is also employed in smaller and more mobile installations, known as suction plants, in which the gas-producer and gas-engine are a single unit. The suction plant, therefore, adapts raw coal to immediate use in the internal combustion engine, combining the efficiency of the latter with the mobility of the steam engine. Thus producer-gas is suitable not only for large service stations, but also for small industrial plants and even for marine engines and locomotives. The manufacture of producer-gas from coke, peat, lignite, and high-ash mine refuse has become so thoroughly established on the continent as to be a commonplace procedure. The widespread use abroad of the producer gas principle has brought into competition with high-grade coals used as such the low-grade coals and coallike substances needed to supplement a limited fuel supply.

The briquetting of low-grade lignitic coals and coal slack has been successfully practiced in Germany and other European countries for over 30 years, thus, together with the results attained by producer gas, bringing into service types of coal largely unused in the United States. A number of special forms of fuel coke, approximating artificial anthracite, have met with some measure of success, especially in England, where they are sold under the trade names of coalite, charco, coalexld, and others.

As a war measure, the belligerent countries of Europe have been forced to take radical steps in order to insure an advantageous use of their coal resources. The French and Italian Governments have assumed complete control of distribution. In May, 1917, the Russian provisional Government took over the coal mines of that country for the purpose of controlling distribution and prices. Early in the war, Germany centralized the entire coal industry under Government control and a recent report states that the use of raw coal has been forbidden. In England, the coal mines are under full Government authority and in addition a board of fuel research has been established which is recognizing both the economic and technological sides of the problem of bettering the service obtained from coal. The steps taken by the United States are well known.[1]

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[1] It is strictly speaking modified or semi water-gas, lower in calorific value than water-gas proper which is made by gasifying coke or anthracite under the action of steam.

In view of the advances in the utilization of low-grade coals abroad, we are led to inquire as to the potentialities of similar coals in the United States, which have heretofore not been called into action because of the prevalence of more desirable grades. Low-rank coals are very abundant in this country as shown by the United States Geological Survey, whose results may be summarized and expressed in round numbers on a per capita basis, as follows:

Coal reserves of the United States calculated to a per capita basis.[1]

	Now underground.	Mined to date.
	Tons.	*Tons.*
Anthracite	190	28
Bituminous coal	15,000	92
Lignitic coals[2]	20,000	([3])

[1] The calculations are made by the writers from data presented by Marius R. Campbell, The Coal Fields of the United States: General Introduction, Prof. Paper 100-A, U. S. Geological Survey, 1917. The figures are given in round numbers based on a population of 100,000,000.

[2] Includes subbituminous coal, which is between lignite and bituminous coal in quality.

[3] Practically untouched.

The deficiency of anthracite and the magnitude of lignitic coals are at once apparent. It has already been shown how the undue dependency on the small and waning anthracite reserve may be relieved by a suitable by-product utilization of bituminous coal. The further application of the same principle would likewise lend significance to our lignitic coals, tending to raise their value from little or nothing to a point justifying their adoption in the place of higher-rank coals in those regions, at least, in which lignites alone occur.[2] And in this connection, it should be noted that lignitic coals occur chiefly in the Dakotas, Montana, Wyoming, Colorado, Arizona, New Mexico, Texas, and Louisiana, in sections largely free from other coal resources.

Considerable experimental work in this country has already been directed toward making lignites effective sources of heat and power. Because of their high moisture content and tendency to "slack," these coals are not suitable for transportation like ordinary coal. Efforts toward burning them in powdered form, with the effect of gaseous fuel, or of compressing them into briquets have met with some success, but their greatest possibilities are afforded through complete gasification in gas producers,[1] or by carbonization with by-product recovery. The Bureau of Mines has demonstrated in respect to the last that 1 ton of air-dried lignite may be made to yield 8,000 to 10,000 cubic feet of gas, 17 pounds of ammonium sulphate, 1 gallon of oil, 50 pounds of tar, and one-half to two-thirds ton of carbon residue convertible into briquets approaching the value of anthracite.[2] Thus may even coals lowest in rank be raised to meet the social needs for smokeless fuel and economy.[3]

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[1] The Federal Trade Commission under date of June 19, 1917, recommended to the United States Senate:

"*First.* That the production and distribution of coal and coke be conducted through a pool in the hands of a Government agency; that the producers of various grades of fuel be paid their full cost of production plus a uniform profit per ton (with due allowance for quality of product and efficiency of service).

"*Second.* That the transportation agencies of the United States, both rail and water, be similarly pooled and operated on Government account, under the direction of the President, and that all such means of transportation be operated as a unit, the owning corporations being paid a just and fair compensation which would cover normal net profit, upkeep, and betterments." (S. Doc. No. 50, 65th Cong., 1st sess., Washington, 1917, pp. 20-21.)

[2] The subbituminous coals are now used to some extent, but inadequately.

V.

While the greatest improvements, with most telling consequences, are possible and necessary in the utilization of coal; the conditions of coal production are likewise not best adapted to the nature of the resource and offer opportunities for advantageous changes. Passing over anthracite, because it is not inherently a necessity and because, moreover, its production is effective both as to engineering practice and coordination of operations, we find that the mining of bituminous coal is so widely scattered and loosely cooperative that the aggregated activities are to be looked upon as an "industry" only in respect to their common purpose.[4] The country's most basic resource, indeed, is produced through the medium of a thousand disintegrated units, working without concert and under conditions of destructive competition.

Bituminous coal mining as an industry is beset by conditions which are the occasion of present wastefulness and the justification of apprehension for the future.[1] Scattered and unorganized, most of the individual companies are small and financially weak; no adequate cooperation in engineering practice exists; new developments are slow of growth; coal is mined for the most part by conservative, long established practice. With no methods of storage developed, the average mine can mine coal only when railroad cars stand ready to receive it; a fluctuating demand, accentuated by seasonal variations, leads to instability of operations; many mines in normal times must close down in slack periods, with destructive effect upon the conditions and supply of labor. For years the price of coal at the mine has been from $1 to $1.15 a ton, a figure so low that only the best and most easily obtainable coal could be extracted by the cheapest methods of mining, irrespective of the waste involved; the tonnage of thin-seam and high-cost areas sacrificed in the process amounts to more than half the total coal produced to date. Many districts have been burdened with a leasing system that obligated the company to remove a given tonnage each year, irrespective of market demand or price, with the result that the richest spots were drawn from seam after seam with irretrievable loss to present needs. Miners' unions in general have fixed wages on the basis of thick and easily worked seams, and imposed such severe penalties upon inferior conditions that the operator is precluded from introducing new and improved methods. Upon all this, the policy of the Government, as exemplified in its anti-trust laws, has forbidden combinations and restrained cooperation, with the result that large-scale, standardized operations, a paramount and distinctive American achievement, is practically lacking in the mining of coal.

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[1] A few producer-gas plants are in service in the lignite areas. A specific instance of the applicability of suction gas-producers would be in connection with the motor boats in service along the Alaskan coast which now use gasoline brought from California, but instead might employ the low-grade coals so plentifu in parts of the Alaskan coastal region. The present attempts at fuel economy seem superficial, when the real points of wastefulness are held in mind.

[2] "There seems little doubt but that the briquetting and the production of gas from lignite can in the near future be put on a commercially satisfactory basis." Babcock, E. J., Economic Methods of Utilizing Western Lignites: Bull. 89, Bureau of Mines, 1915, p. 65.

[3] We may profit by the words of a distinguished British engineer and chemist, the late V. B. Lewes, who writes of the coal of England:

"Among the factors that lead to the commercial supremacy of a country by far the most important is the command of fuel or other source of power; and England's position in the past has been governed largely by her coal fields, which in little more than a century raised her to the forefront as a commercial power. The very abundance of our coal supplies was a source of weakness, as it led to outrageous waste, polluted our atmosphere to a criminal extent, and so encouraged uneconomical methods of using it as seriously to deplete our available stock, the result of which has been the increase in price during the last few years, and the certainty that the future will see further advances but no fall to the old rates. The day of cheap coal has gone, never to return."

[4] The coal industry in its operations is more comparable to the brickmaking industry than, for example, to the iron industry.

These conditions are particularly objectionable because they concern a product of fundamental importance. As compared with the iron industry or the copper industry, the coal industry appears in an unfavorable light in production efficiency. The difference is not to be attributed otherwise than to the competitive system of small-unit mining, which has prevailed for coal in this country and indeed been perpetuated, against a natural tendency otherwise, by a public policy hostile to combination.[2]

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[1] "For several years prior to 1916 it was a matter of general knowledge that the bituminous coal industry in the United States was in an unsound condition. In this basic industry, so necessary to the industrial life of the country, conditions had developed so that it was demoralized financially, wasteful methods of mining resulted in the permanent loss of millions of tons of coal that could have been saved otherwise, the existing mines through lack of demand were kept idle from one-fourth to one-third of the working time, with consequent hardship to labor." Letter from Federal Trade Commission on Anthracite and Bituminous Coal, S. Doc. No. 50, 65th Cong., 1st sess., Washington, 1917, p. 43.

[2] The individual coal producer can not he held responsible. In any attempt to recover more coal; that is, to make real progress in coal mining, he faced the opposition of the miners' unions, of governmental restrictions, and of probably financial loss. The three formed usually an unsuperable obstacle, although a considerable advance was attained in many creditable instances. If European coal mining conditions were impeded as the industry is in the United States, the industrial activities of Europe would come to a stand-still, if the continent would not actually starve to death.

Coal can not be mined effectively under the present system. The nature of the resource demands integration. Only by the grace of lavish coal wealth has the United States this long borne the incubus of competition in coal mining. So much is generally recognized, but the means whereby integration may be attained are less apparent. The most practicable path leads toward the enlargement of the public utilities conception to embrace coal.

We may define a public utility as a necessity which does not lend itself to competition. In such a category fall gas, water, and electricity, the telephone service and traction systems of municipalities. In the case of these necessities, public regulation is substituted for the restraining influence of a competition that has been found inexpedient. Coal is a necessity which does not lend itself to competitive mining.

In anthracite is found an interesting spokesman of this principle. The anthracite industry began with many competing units, but the smallness of the field made combination easy and led to the merging of the rival interests in a unified organization. The purpose of the combination, judged by the results, was twofold; to raise the price of anthracite and to increase the efficiency of mining. The disadvantages of the first was commonly recognized, but not the advantages of the second, which were equally significant. Through its monopolistic control of a recognized necessity, the combine years ago became a matter of public concern and the Government faced two alternatives in meeting the problem thereby raised—it could either recognize a combination in restraint of trade, and order its disintegration; or else accept the combination as a procedure essential to the proper handling of the resource, and impose suitable restrictions on the basis that the activity had become automatically a public utility. The first procedure was adopted and the combine was dissolved in so far as its legal existence was concerned; but at bottom the combination persisted, because it was inherent in the nature of anthracite development and could not be legislated out of existence.[1] The alternative chosen by the Government was impossible of execution. It is open knowledge that the anthracite companies to-day operate in concert and fix prices by circular announcements at rates suitable for the effective operation of both high-cost and low-cost mines. As a result, anthracite is mined efficiently in spite of laws opposing the means to that end.

The bituminous industry deals with a necessity that is lending itself less and less to competitive production. Competition is incompatible with economy, because coals expensive to mine can not compete on a commercial basis with those which may be mined cheaply, and the two, in general, occur in such intimate association that the first, under present conditions, must be sacrificed in order to get the second. If the price is arbitrarily fixed high enough to cover the extraction of high-cost coal, society will pay too much for low-cost coal. If, on the contrary, the price is allowed to seek a natural level, the high-cost coal can not be extracted and much of it becomes permanently lost. It may be asserted that we should use up the cheaply obtainable coal first and then later, when necessary, turn to the coal more expensive to produce. Such would be advisable, were it not for the fact that the fat and the lean occur intimately mixed, and we can not later return and glean the unused values. This limitation is set by the geological occurrence of coal and can not be changed. The only way by which coal can be mined effectively is for the price to be adjusted to the mining costs of each mine, and even to those of different parts of the same mine. Obviously, this would require a pooling of interests—in short, integration.

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[1] Writes F. W. Taussig, in a different connection: "The large outstanding fact is the collapse of competitive industry. Combination and monopoly are the inevitable result of the machine processes and large-scale production. Legislation can not prevent monopoly. ..." Principles of Economics, New York, 1911, p. 442.

Bituminous coal, therefore, is a necessity which can not be produced advantageously under competitive operation. It has become by its very nature a public utility, and its administration as such, with integrated activity, is the only practicable way by which its full service can be secured.

Integrated coal mining, under proper limitations, will reduce waste, stabilize production, adjust supply to demand, lessen transportation, and hold the centers of coal production longer than otherwise in their present spots to the advantage of the present distribution of industrial activities, but can not be expected to lower the cost of coal to the consumer. For that purpose, as already pointed out, far-reaching changes in coal utilization alone will suffice. While the price of coal to the consumer has been too high, the price of coal at the mine has been, in general, too low—so low in fact that it has been a small factor in the ultimate cost to the public. That is evident in the contrast between one dollar and the figure the consumer pays. The price of coal at the mine mouth, however, has been slowly advancing; the upward tendency is natural and if left to itself will become stronger and stronger as more and more of the easy-to-get coal is mined. At the present moment the price at the mine is too low, because of the apparent abundance of easy-to-get coal; but within a very few years (if not already), with the exhaustion of cheaply mined coal, the mining costs are bound to attain a rank more consequential in effect upon the ultimate price. It is even now very generally conceded that the "day of cheap coal is over." While integrated mining would add slightly to the average ton-cost of coal at the mine, the effect would be to relieve the further upward tendency from the acute increase which present conditions will inevitably create. The result, in fine, will be to prolong to the utmost the period of cheap coal.[1]

The advantages of integration in coal production are well known in other countries. The thin seams of the eastern coal fields of Canada can only be worked under a cooperative system, as pointed out by the Canadian Department of Mines. Belgian mining law imposes the obligation of cooperative measures upon the coal-mining concessionaire. Cooperative coal marketing has been successfully practiced in many parts of the world, notably in Germany and in the Transvaal.

In short, coal as a resource demands cooperative measures of development. This is true of coal in peculiar degree and holds equally for no other resource. The reason is twofold. In the first place, coal deposits do not lend themselves, as do many other types of mineral deposits, to a graded extraction of values according to the strength of economic demand. In the second place, coal as the major source of power is the basis of modern life, and as such imposes upon organized society a direct responsibility to insure its most effective disposition.

VI.

Coal is a resource requisite to the functioning of every other resource. The home, industry, and commerce are entirely dependent upon its adequacy. Coal is the basis of organized life. Other raw materials are merely parts of the social fabric—incidental to it; iron, for example, does not come to the consumer as such; but coal is comfort and energy as well as a commodity to be manufactured. Coal, therefore, in its far-reaching consequences, has assumed a responsibility equalled by no other substance.

Under present conditions, coal fails to measure up to that responsibility. It is wastefully mined, wastefully distributed, and wastefully utilized. It is wastefully mined because of the conditions of competition which society imposes upon its exploitation. It is wastefully distributed as a result of the unnecessary transportation in regions supplied with water power or with coals less desirable than those consumed. It is wastefully used due to the lack of by-product recovery as an accepted economic practice.

The wastes in mining may be decreased through integrated operations, which will obviate the economic necessity for waste. Coal submits itself to integration as a public utility.

The wastes in distribution may be reduced through the development of hydro-electric power, thus relieving coal of unnecessary duties, and by improvements in utilization, thus destroying the overdependence upon high-grade coals which now necessitates undue haulage.

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[1] It need scarcely be pointed out the advantages of by-product utilization may be realized without the gains of integrated mining, but the first may be largely nullified through the neglect of the second.

The wastes in utilization may be done away with by establishing a method of separating the energy-producing constituents of coal from the commodity values and using the products to their common advantage. The most logical point of attack is the municipality, to which may be attached a public utility plant converting raw coal into smokeless fuel—artificial anthracite plus gas, or gas alone—and valuable by-products, ammonia, benzol, and tar. Such a plant would supply the fuel needs of the community and ship the surplus by-products to serve as raw material for a coal-products industry, developed thereby to proportions consistent with its importance to social progress.

Integrated mining will lessen the increased costs that will come with the impending extraction of thick-seam and easily obtainable coals.

Reduced coal transportation will remove an unnecessary burden from the railways and prevent the repetition of the congestion difficulties so acutely felt during the winter of 1917–18.

By-product utilization will give cheaper fuel through the advantageous disposition of all the values contained. It will also end the smoke nuisance, relieve transportation, and cause the growth of a great coal-products industry with ultimate possibilities ranging beyond the grasp of the imagination.

This paper does not presume to set forth the exact methods whereby these results may be attained; the procedures remain to be worked out in detail. Its purpose, however, has been to present a line of attack, drawn up on the basis of the character and extent of the resource, which may be followed to specific advantage. There are no serious technical obstacles in the way; the chief requisite for progress is a popular appreciation of the fact that coal contains greater values than society is getting from it. From this realization will spring a public demand that scientific and technical knowledge be used, not merely in making improvements in the details of present practice but in revising that practice itself and shaping a policy of administration more in keeping with what is known to be the potentiality of coal. ''Mankind,'' writes John Dewey, ''so far has been ruled by things and by words, not by thought * * * . If ever we are to be governed by intelligence, not by things and words, science must have something to say about *what* we do and not merely *how* we may do it more easily and economically.''[1]

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[1] It should be borne in mind that fundamental changes in coal economics are capable of just as much harm if handled ill-advisedly as of good if competently directed. Unless a type of public management superior to anything this country has developed in the past can be put forth, the whole matter might better be left in its present state of inadequacy.

And, in conclusion, it may be asked what are the assets and the liabilities in this business of demanding a full accountability from coal. Here is the balance sheet:

Assets:	Liabilities:
Ample coal resources.	Tradition.
By-product coke experience.	Character of the past administration of the average public utility.
Municipal gas-plant installations.	Character of our past conduct of technical matters.

The assets are large, but the liabilities, it must be admitted, have been insistent enough to block progress in the past. Whether they will continue to overbalance the assets will depend upon the course of public opinion. It is up to the man in the streets to determine which shall prevail. A continuation of the present system of coal economics may be justified on the basis of indifference to progress, but not on the basis of ignorance; its unnecessary prolongation should afford a prospect intolerable to the thinking man.

PUBLICATIONS OF THE DIVISION OF MINERAL TECHNOLOGY, U. S. NATIONAL MUSEUM.

Bulletin 102, Part 1. Coal Products: An object lesson in resource administration, by Chester G. Gilbert. Issued Nov. 17, 1917. 16 pp., 11 pls.

Bulletin 102, Part 2. Fertilizers: An interpretation of the situation in the United States, by Joseph E. Pogue. Issued Oct. 10, 1917. 22 pp., 1 pl.

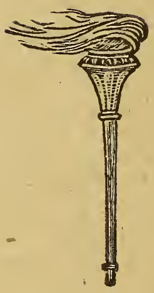
Bulletin 102, Part 3. Sulphur: An example of industrial independence, by Joseph E. Pogue. Issued Nov. 7, 1917. 10 pp., 1 fig., 3 pls.

Bulletin 102, Part 4. Coal: The resource and its full utilization, by Chester G. Gilbert and Joseph E. Pogue. Issued ———, 1918. 26 pp.

Bulletin 102, Part 5. Power: Its significance and needs, by Chester G. Gilbert and Joseph E. Pogue. (In preparation.)

Bulletin 102, Part 6. Petroleum: A resource interpretation, by Joseph E. Pogue and Chester G. Gilbert. (In preparation.)

NOTE.—The papers listed above are members of a series entitled, The Mineral Industries of the United States.



SMITHSONIAN INSTITUTION
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Bulletin 102, Part 5

THE MINERAL INDUSTRIES OF THE UNITED STATES

POWER: ITS SIGNIFICANCE AND NEEDS

BY

CHESTER G. GILBERT
AND
JOSEPH E. POGUE
Of the Division of Mineral Technology
United States National Museum

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CONTENTS.

Page.
Influence of power upon civilization 7
Relation of power to transportation 9
Principles of transportation as applied to power 12
Full utilization of power materals 15
  Rôle of multple production 15
  Relation of multiple production and electricity 21
Power resources and advance elimination of weight 21
Facilities of transportation as applied to power 32
Correlation of water power and coal power 35
Nationalization of industrial opportunity 38
Enlargement of industrial opportunity 42
Summary 47

FOREWORD.

Mineral resources are coming more and more into prominence as the basis upon which modern advance is built. Their adequate development is a matter of the first importance, and public opinion will be called upon in increasing measure to shape the course of advance in this fundamental field. As the general subject is not one of popular experience, this series of papers is under preparation for the purpose of interpreting in nontechnical language the significant aspects of each resource of mineral origin, in anticipation of a growing demand for concise summations of technical knowledge in a form adapted to current use.

The sources of energy underlie the employment of all raw material, and this paper on power, together with those of this series on coal and petroleum, are designed to present a constructive analysis of the fuel situation in the United States.

POWER: ITS SIGNIFICANCE AND NEEDS.[1]

By Chester G. Gilbert and Joseph E. Pogue,
Of the Division of Mineral Technology, United States National Museum.

INFLUENCE OF POWER UPON CIVILIZATION.

In the struggle for existence man has attained superiority through a facility for turning the forces of nature to account. In modern life the expression of this facility is industrialism—the cooperative employment of mechanical power for useful work; the delegation of service to machines energized by coal, oil, and water power; the organized gaining of a livelihood. Mankind is therefore dependent upon industrialism and industrialism is contingent upon a supply of power.[2] Power represents the substitution of mechanical energy for human energy, of mechanical work for human labor.

Modern nations expend far more energy than the combined muscular ability of their populations and beasts of burden. The margin is covered by the employment of mechanical energy in the form of power. To accomplish the work done annually in the United States, or at least the equivalent in such kind as men could perform, would require the labor of three billion[3] hard-working slaves. The use of power gives to each man, woman, and child in this country the service equivalent of 30 servants.[3] Modern civilization arises from this organized employment of mechanical energy.[4]

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[1] A contribution to the solution of the transportation problem.

[2] Industry requires raw materials, power, and labor, and is activated by business enterprise. The factors concerned in the supply of raw materials and power are no less important than the human elements of labor and business enterprise, though the former have thus far received attention far short of their deserts. The fact that the reserves of raw materials are decreasing and the conventional sources of power are shifting, while both the potential supply of labor and the scope of business enterprise are enlarging, make for a situation in which raw materials and power must come in for considerable attention. It is with this prospect in mind that the present series of papers (parts 4, 5, and 6 of Bulletin 102) have been written.

[3] These figures are very rough, based on an assumed power utilization of 150,000,000 horsepower (which may be fairly wide of the mark) and the equivalence of 20 man-power for 1 horsepower. As a matter of fact, this country has no adequate record of its total power consumption. The conventional man-power equivalent of 1 horsepower is 10, but taking into account the fact that man-power can not be sustained, the ratio of 20 to 1 is chosen as representing a fairer comparison.

[4] "The power of Greece, whereby she achieved such great things in all directions of human progress, was largely based on the work done by the servile class. On the average each Greek freeman, each Greek family, had five helots whom we think of not at all when we speak of the Greeks, and yet these were the men who supplied a great part of the Greek energy. In Britain, we may say, each family has more than 20 helots to supply energy, requiring no food and feeling nothing of the wear and tear and hopelessness of a servile life." (James Fairgrieve, Geography and World Power, 1917, p. 316.)

The social response to the use of power is a departure from the individualized self-reliant order of livelihood and a steady advance toward the centralized integration of service which we now know under the familiar guise of industrialism. Whether taken in the whole or viewed in a single community, the outcome is the same. An example drawn from pioneer conditions will serve to illustrate the simple course of development. A machine suitable for doing the work of several hands is capable of filling the needs of several individuals. Introduced into a community dependent upon hand labor, such a labor-saving appliance tends to centralize the work falling within the scope of the machine. The operator, becoming proficient and finding himself looked to for an increasing measure of service, adds to his equipment. At the outset he performs only the work brought to him by individuals in the community, who supply the raw materials and receive in return the finished products. Soon, however, the competence of the machine becomes more widely recognized and the operator is commissioned to supply the raw materials as well as the service. Presently, again, with the recurrence of such commissions, the operator goes further, and instead of awaiting specific commissions assumes the initiative in providing both raw materials and service in anticipation of demand, and thus an industry, in the current sense, is launched. Such has been the run of evolution in the rise of industrialism, and wherever individual work persists to-day it is in process of giving way in favor of the community operation.

The use of power not only leads to centralization of work, but the form in which power is available determines the type of industrialism or civilization that develops. Considering energy apart from its sources, we find that this force has come into use in three mediums of expressions—liquid, gaseous, and nonsubstantial—typified in hydraulic power, steam power, and electric power. These steps in energy usage represent progressive stages in facility of employment and indicate an evolutionary trend underlying the industrial unfoldment to which they have given rise. Thus the use of hydraulic power marks the period of individualism which prevailed the world over until the eighteenth century, and still holds in all but the so-called civilized nations; the application of steam power instituted a change so profound as to merit the name "The industrial revolution," and colored the whole face of modern civilization during a stretch of time, extending to the present, which may be termed the formative period of industrialism; while the introduction of electric power brings forward a third advance in power usage offering to the maturing aspects of industrialism a special service needed to carry forward its complex and constantly enlarging activities. Just as steam power opened up the coal fields of the world and freed the employment of power from the geographic restrictions inherent in the use of the pressure of falling water, so electricity reinstates water power on terms of equality with coal, offers the means for the transmission of energy devoid of bulk, and affords a readiness of subdivision and ease of application that considerably enlarges its range of applications.[1]

Thus the third and current stage in the growth of power utilization, and that is to say, of industrialism, is marked by the introduction of water power on terms of parity with coal, by the establishment of facilities for extracting energy from coal at the mines and transmitting it to the points of use, and by the development of means for greatly facilitating the range of service that energy may be called upon to render. It will be observed that although the three lines of advantage have been open for some years, the first has met with but partial acceptance, the second has been entirely ignored, while only the third has enjoyed any considerable measure of service. This status of affairs, of course, is the outcome of commercial selection, but it is desirable to examine whether industrialism can continue to grow in adequate measure without utilizing more fully and comprehensively the opportunities held out by electricity.

RELATION OF POWER TO TRANSPORTATION.

The United States places special emphasis upon the use of power. With national prosperity, abundance of resource wealth, and dearth of labor, American industrial enterprise has naturally turned to the creation of labor-saving machinery and provided for its efficient employment through the medium of standardized volume-production. Thus the fabric of American industrialism is colored by the machine process and the large-scale operation to a degree not equalled elsewhere in the world; while mechanical appliances and mechanical service have reached out into domestic life in a pervasive manner. These conditions have created and sustained a scale of living without parallel amongst other nations. To support this situation, this country consumes nearly half of the world's output of coal and over half of the total production of petroleum, not to mention the employment of water power, natural gas, and minor sources of power.[2]

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[1] The advantages of electricity arise from the fact that this strange and even mysterious manifestation of energy is virtually energy itself—not energy locked up in a material condition and subject to the laws and limitations of matter, but energy, the capacity to do work, freed from substantial form.

[2] Of the coal and oil consumed, only about two-thirds goes into the production of motive power, although much of the service outside this field is closely related, such as the production of heat, light, and chemical work. Before the war the consumption of coal in this country was between one-third and one-half of the world's total; the proportion is now approaching one-half.

This unprecedented consumption of power, of course, places a heavy strain upon transportation, both directly by virtue of the bulk of the power materials to be moved—coal alone represents over a third of the country's freight—and indirectly in respect to the haulage of materials and products involved in the industrial processes. The responsibility thus falling upon transportation is added to in further degree by the size of the country. The presence of a population scattered over a vast area, with a standard of consumption cut to the measure of a concentrated industrialism, attaches the element of distance to the factor of bulk and imposes an accentuated dependence upon adequate carriage.[1] Thus in two respects the transportation problem in the United States is unique.

But national dependence upon transportation, so highly developed by virtue of the advanced state of industrialism and the areal extent of consumptive demand, is increasing. The rapidly enlarging use of power and the growing burden of commodity haulage arising in consequence, to say nothing of the claims of foreign trade, give no prospect of letting up. Every time an individual adopts a mechanical appliance or purchases an article hitherto made at home or gone without, thousands of others are doing the same thing. Society will not turn back now; presently it can not turn back any more than it can to-day weave its own garments by hand. The convenience of to-day is the necessity of to-morrow. If we project the present trend of requirements even 10 or 15 years into the future, we begin to gain a true perspective of the imposing weight of the transportation problem that industrialism faces.

Since transportation is called upon to bear a heavier responsibility in the United States than is the case elsewhere in the world, it should be observed that there is an element of weakness in the functioning of transportation which becomes the point of break under strain and therefore merits particular attention in this country. This is the matter of differential elasticity as between the operations of industry and transportation, which prevents an equalized stretching of the two. For example, when a ton of material passes through a manufacturing plant it means, with due qualifications, that the railroads have hauled a ton of raw material from far and wide and will move a similar weight of products away for distribution. Thus each increment to the volume of manufacture creates a twofold addition to the volume of transportation. Induce a stress of industrial expansion and the stress communicated to transportation is correspondingly magnified. The fabric is mechanical in each case; but the fabric of industry is woven with the maximum of elasticity, while the fabric of transportation is inherently more rigid. Thus one of the knottiest problems in the whole advance of American industrialism has been involved in the necessity for providing the requisite capacity on the side of transportation. The problem is serious enough at best. But when the item of power in the form of freight-hauled coal is added, the requirement calling for additional elasticity in the mechanism of transportation is almost doubled a second time, and the situation becomes well-nigh impossible to meet. So long as power is provided by means of freighted coal in its present heavy proportion, the transportation of the country is bound to cause serious trouble, if not to break down, during every period of sudden industrial expansion.

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[1] This has nothing to say of further complications in the way of conflicting currents of haulage arising from topographical conditions, etc.

The relations of balance, as given above, are not in strict accord with statistical figures. Various other factors come in to qualify the figures, and incidentally to complicate the issue beyond the reach of simple analysis. Nevertheless the contrast noted is indicative of the general situation. The requisite degree of elasticity has not been attainable for transportation, and the lack of it has become increasingly conspicuous with the growth of the industrial order. The tendency has been to provide a surplus of slack in lieu of elasticity by maintaining facilities of transportation in excess of normal requirements. Such a condition constitutes a standing invitation to inefficiency and wastefulness, tending in the long run to nullify the potential advantage of readiness for industrial expansion, and hence is forecast for failure when put to the test. With industrialism less mature and less aggressive, these matters were less conspicuous, but their untoward propensities under present conditions of growth are becoming steadily more pronounced.[1]

Thus transportation is the neck of industry through which all of its materials enter and emerge. Upon the size and flexibility of this throat depends the rate at which industry can grow. Pressure here acts as a throttle; if severe, there results congestion, choking, even strangulation. Transportation, then, is crucial. Either we must pay unremitting attention to facilitating transportation by every means available, or else be prepared to see industry retarded and slowed down at this point, with a fall in the scale of living and a change in the color of national advance. Thus far this country has attempted to meet this issue almost solely by means of railways, and has ignored the bearing upon the matter of the item of power, although this ingredient engages over a third of the freight capacity of the country and is a prime contributor to the inelasticity of the transportation fabric as now woven. From a broad viewpoint, it would appear that the transportation problem can not be adequately solved without giving due attention to the question of power.

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[1] The current situation in the United States does not differ fundamentally from that abroad, although the consequences have not appeared in equal measure in the two instances. The disparity is one of degree; but the unusual weight falling upon transportation in the economics of American industrialism has turned this difference into high significance. The outcome appears in present conditions: the United States has been building a bulky and cumbersome fuel requirement, incapable of sustained growth, ready to fail under influence of rapid industrial expansion, and due to display its weakness, on the first occasion in the breakdown of organized transportation. This is not to be regarded as offered in specific explanation for the trouble that this country is now experiencing as an incident in the war situation. As a matter of fact, the present work was projected over a year ago and the summation of conditions set forth above was outlined at that time. Its purpose in respect to present difficulties is in the direction of diagnosing an organic weakness which rendered the country peculiarly susceptible to attack by the disrupting influences now so unconcernedly borne on the basis of a passing trouble.

Conversely, power itself presents a problem of no small magnitude, since without adequacy in this respect the processes of industry are idle. It is common notoriety that the limiting factor in the supply of power is not a dearth in energy resources, of which, indeed, this country is amply provided,[1] but lies in the means for getting the energy distributed to the points of use. The importance of the transportation side of the power problem is reflected in the country-wide system of pipe lines for the service of petroleum, and the concentration of industry in regions provided with coal—both concessions to the exigencies of carriage.

Thus, since the transportation problem embraces the matter of power, while the power problem displays itself mainly in the guise of transportation, the two issues merge, and whether viewed from the one angle or the other, the logical objective for an attack is presented in the form of power transportation.

PRINCIPLES OF TRANSPORTATION AS APPLIED TO POWER.

Organized transportation differs essentially from the simple individual act of carrying only in magnitude. The underlying principles are the same in the two extremes. Whether the concern be that of a stone in a neighboring field or a mountain of copper ore a thousand miles distant, effectiveness of transportation involves the same three factors. These are:

1. The employment of the equipment best suited to the task.
2. The advance elimination of superfluous weight.
3. The full utilization of the material transported.

The individual encounters these principles at every move and habitually follows their promptings in conserving his personal efforts. The operation of industry as a whole is also fashioned in conformance with them. The developments in the case of power supply provide the only noteworthy exception. Here the practice is at variance, not merely with one of the principles, but with all three of them. The energy in coal, for example, is not concentrated before shipment, but is hauled in its substantial, bulky form; while the coal at its destination is not used so as to yield anywhere near its full service.[1] With industry in general, conformance with these three principles has been automatic, a natural outgrowth in connection with the development of the various types of operations; with power supply, on the contrary, a sufficiency of natural incentive toward such an outcome has evidently been lacking. It is desirable, then, to seek to determine what is back of this apathy in the exceptional instance of power.

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[1] So large are the energy resources of the United States that their very size has made it seem unnecessary even to regard power as a national problem. Hence the problem has actually come to a head in all its seriousness, without any symptoms having generally been recognized in advance.

The first of the three principles of transportation, the employment of suitable equipment, involves a community interest. The facilities best suited for bringing to the market the corn raised by one farmer will haul grain from the entire corn belt with equal ease. Moreover, with slight qualification, the same facilities will serve to transport all the material necessities of the region. Hence there have developed common-carrier systems, represented chiefly by the railways, to which the performance of this function is delegated. These common-carrier systems, it is needless to say, are essential to modern conditions and derive their existence from the community interest which they represent. In consequence, the element of competition, which is the exact antithesis of community interest, is entirely out of place within the confines of such an activity. In the nature of things, accordingly, any response to the promptings of special interests amounts to a violation of a trust. Formerly this was not fully realized, and it has not been long since the evil influence arising from the promptings of special interests within the great common-carrier systems of the country was playing havoc with American industrialism. It is now firmly established, however, that the great arterial complex of transportation is founded on the principle of community interest and must be maintained in scrupulous accord with that principle. In the violation of this trust a common carrier has in itself the power to make or break any industrial enterprise, hence the method of control must afford the maximum assurance that the trust will not, and can not, be violated. Thus the successful application of the first principle underlying effective transportation, from a national viewpoint, requires a common carrier system not only adequately equipped as to organization and mechanical facilities, but of public-service integrity established beyond question of doubt.

The second principle of transportation, the advance elimination of superfluous weight, is a matter requiring individuality of treatment throughout. The conditions here are the reverse of those pertaining to the actual facilities of transportation. The responsibility attaches to individual activities; there is no community of interest in the matter; the responsibility may be ignored, but it can not be delegated. In the realm of industry, competition affords the incentive for meeting this responsibility. The incentive, in general, has been sufficient for all practical purposes, and the specific application of this principle constitutes one of the chief interests in the shaping of industrial enterprise. Since power is a mineral derivative, the mineral industries provide a logical field for comparison. Here is found scarcely an instance of consequence where the raw mineral values are not concentrated to their utmost before shipment and where every available refinement of procedure is not employed toward the advance elimination of weight. The whole field of ore dressing has grown up under the incentive of this principle, not to mention the applications of metallurgy in this respect. The only noteworthy exceptions occur in rare connections, where competition for the placement of the end-products is a negligible factor.[1]

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[1] See Coal: The resource and its full utilization, Bulletin 102, part 4, of this series.

The third principle of transportation calls for the full utilization of the material hauled. American economic practice has regarded this, along with the advance elimination of weight, as a matter to be left to industrial determination and application. This policy is natural enough and, in general, works out satisfactorily, for the two principles are complementary. What is usable at the manufacturing end obviously determines what represents value and non-value at the raw material source; conversely, the degree of separation practicable at the source specifies the range of material for which use is to be sought. The whole epoch-marking development in the field of by-product manufacture finds much of its stimulus in the effort to derive returns from what would otherwise be the waste in transportation. But, with certain notable exceptions offered by some of the large industrial combinations, there is much to be desired and little to be proud of, so far as American achievement in this direction goes. The superfluous transportation that results from the failure at the manufacturing end to make full utilization of the whole range of values held in the raw material hauled amounts to many millions of tons each year. Instances are plentiful where the loss is due to a blind nonrecognition of opportunity on the part of the interests directly concerned. But in the main the default rests upon the inadequacy of American economic practice, which relies upon competition and the automatic working of the natural law of supply and demand to bring all good things to pass, neglectful of the fact that in the by-product realm supply is conditioned otherwise than by demand, that pending the creation of a proportionated demand the discrepancy of overweight on the side of supply is rejected as waste.[1]

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[1] Perhaps the most notorious example of failure on this score is afforded by anthracite coal during the past season, when millions of tons of waste slate were permitted to accompany the outgoing shipments of coal from the mines. The same thing was essentially true of bituminous coal during the past winter, only, as bituminous coal in the natural state is cleaner in respect to slate than is anthracite, the relative proportion of waste hauled was less in the case of soft coal. The outcome, then, should be accredited more to natural conditions than to lack of enterprise in this direction on the part of the bituminous producers, who, in common with the anthracite producers, displayed a ready response to the temporary nullification of competition as regards the placement of their products.

In such manner have the three principles of transportation developed in American economic practice. In the realm of common carriage, competition has been found to be out of place and is no longer relied upon, community interest taking its place. In the realm of advance preparation, competition has proved effective; and its free operation there is desirable. In the realm of full utilization, competition alone has been unable to achieve adequate results; and the need for constructive help to make competition effective here is coming to be recognized. These principles have registered among mineral resources in the main; they have failed dismally to find lodgement in the field of power resources. It remains to determine why the contrast and what the remedy. In the attempt, the three aspects of the situation will be considered in the reverse order of their presentation above.

FULL UTILIZATION OF POWER MATERIALS.

RÔLE OF MULTIPLE PRODUCTION.

The power materials are coal, oil, and water, and, in the present connection, it is desirable to examine how fully the amount transported is utilized. Water, of course, is not carried considerable distances for purposes of power generation and therefore presents no problem in this connection. Oil, on the contrary, is in part inadequately utilized, but this matter involves many complexities, which are given in detail elsewhere[2] and accordingly may be passed over without further comment here. This limits our consideration, under the present head, to coal.

Current demand calls for the annual transportation and distribution of about 700 million tons of coal.[3] Much of this demand could be satisfied with no other commodity or form of energy, while any change in the part open to modification can take effect only slowly.

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[1] This important matter is examined in greater detail in Petroleum: A resource interpretation, Bulletin 102, part 6, of this series, pp. 67–70.

[2] Petroleum: A resource interpretation, Bulletin 102, part 6, of this series.

[3] In 1917 this country produced 640 million tons, but the requirements for 1918 will be over 700 million. While roughly only two-thirds of the output is used for power generation, the other third being employed for the manufacture of coal products (chiefly coke) and for domestic heating, the principle of full utilization applies to the total amount.

Meanwhile the demand is increasing at the rate of some 50 million tons each year.[1] The expansion in new consumption, then, may fairly be expected to offset any curtailment in bulk that betterment of procedure may permit. The best that may be hoped for is a check in the growth of the coal burden under which organized transportation is already staggering. To let this burden freely continue to increase, trusting the outcome to luck, is to court all kinds of trouble, if not disaster; yet, even with best effort, there is little prospect of a diminishing requirement.

It would appear, therefore, that at best we must continue to deal with over a half billion tons of coal. This figure, then, may be taken as representing the minimum of actual demand that must fall upon transportation, the minimum of tonnage whose full utilization in consequence is called for. Primarily this enormous amount of coal is now consumed in order to gain the energy contained in it, all else being disregarded. But coal is something more than energy in material form; it is also a source of many valuable mineral products. Indeed, it is a veritable treasure house of values, in this regard far surpassing any other type of mineral substance.[2] Upward of a thousand coal products are in use to-day, some of them filling needs less conspicuous but every bit as vital as that for fuel. And the development is still in its infancy. A few years ago and few of these products were known. Chemical vision can see no limit to the further unfoldment in prospect. The boundary to this field is like the horizon, always in sight but never to be reached. There can be no full utilization of coal which fails to take these matters into account.

At the present time a very small proportion of the coal consumed is adequately used. Putting to one side anthracite, which has an energy value merely[3] and therefore yields a reasonable service in its crude state, and counting off about one-twelfth of the bituminous coal, the portion subjected to by-product recovery in connection with the manufacture of coke, we find that there still remains each year in round numbers a half billion tons of coal which are consumed in the raw condition with a total loss of the commodity values and an incomplete recovery of the energy. The sum total of this loss represents the margin between present attainment and full utilization, and may be presented in tabular form, as follows:

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[1] It is estimated that the needs of 1918 will call for nearly 100 million tons in excess of the production of 1917, but the current rate of increase is probably exceptional.

[2] With the possible exception of petroleum.

[3] Its commodity values were lost in the course of its strenuous geological history.

TABLE 1.—*The neglected opportunities involved in the wasteful use of coal in the United States.*

[All figures in round numbers and on an annual basis.]

PRESENT ATTAINMENT.		POSSIBLE ATTAINMENT.					
Coal inadequately used under present conditions (1918).	Recovered under present conditions.	Available under present technical knowledge and ultimately recoverable under stimulus of constructive economic policy.		Loss interpreted in terms of dollars on basis of normal (1915) values.	National meaning of loss under present circumstances.		National gain from correct practice.
500,000,000 tons.	A small percentage of the energy.	Energy.....	At least double the present recovery. (On basis of widespread utilization of gas in place of solid fuel, etc.)	$1,000,000,000+ in needless mining and transportation of coal.	Needless burden upon overworked railways. Smoke nuisance in cities, entailing untold destruction of civic betterment attainments. High cost of coal to consumer. Resource waste.		Some relief to transportation. Complete elimination of smoke. Cheaper fuel.
		Nitrogen (ammonium sulphate).	5,000,000 tons. (On basis of 20 pounds per ton coal.)	$280,000,000........	Serious nitrogen problem affecting field of fertilizers and explosives. Dependence upon Chile for sodium nitrate. Large expenditures for atmospheric-nitrogen plants. High cost of nitrogenous fertilizers, reflected in cost of food.	Inadequacy of coal-products industries. Problems in explosive manufacture.	Nitrogen independence, contributing to food production and explosive manufacture.
		Benzol......	1,000,000,000 gallons. (On basis of 2 gallons per ton coal.)	$300,000,000........	Undue dependence upon gasoline as motor fuel, contributing to overproduction and rapid exhaustion of the petroleum resource.		Contribution to supply of motor fuel. Advancement of good-roads movement. Establishment of large coal-products industry. Gains in new directions to be developed by chemical research.
		Tar.........	4,000,000,000 gallons. (On basis of 8 gallons per ton coal.)	$100,000,000........ Additional value of coal-products manufactured from benzol and tar.	Neglect of roads.		
		Total..	....	[a]$2,000,000,000.....	....		Capacity for relieving cost of living $10-$20 annually per capita. Gain to American industry.

[a] This figure is given as a concrete expression of the magnitude of the opportunity that faces this country in respect to coal, although the significance of the prospect is conveyed more truly in the two columns to the right. The matter, of course, can not be expressed in figures without qualifications, which, therefore, must be accepted on a basis of the argument in the text. An element of double count in the summation is compensated by increments resulting from the course of advancement in multiple production.

The question naturally arises, why this preponderant inadequacy in coal utilization? This is no simple matter to explain: the reply that the individual user, whether an industry, a community, or a householder, finds it cheaper to consume raw coal than to dispose separately of its various values is true, but superficial. That procedure is not cheaper for the users in the aggregate; also there is no lack of technological knowledge requisite to fuller recovery of the values in coal. The shortcoming, then, can not be due to lack of desirability or to lack of technique. The default must be credited against economic conditions. And since the United States in the past has possessed no activities engaged in shaping and stimulating industrial developments, the responsibility reduces itself to the fact that industrial enterprise has not seen fit to go into the matter. Either the opportunity has not been apprehended or industrial enterprise, cognizant of the situation, has not been interested. The latter is undoubtedly the true explanation.[1] For this lack of industrial initiative a blend of several factors is responsible. In the first place, America has been full of opportunities for volume production, and consequently business enterprise has not been forced by the stress of narrowing industrial opportunities to turn to the far more complex field of multiple, or by-product, production; only where the opportunities afforded in this direction were outstanding and marked has the inducement been responded to.[2] Secondly, any given project, on contemplating the prospect, faced a situation in which the establishment of production would yield by-products, the consumption of which required other industries which in turn would contribute other products calling for still further activities; hence a project at the source would undoubtedly see their contemplated output ranging off into hypothetical regions not yet established; while a project, viewing the matter further out, would regard its proposed position as bearing some resemblance to an island in a sea of nondevelopment. The requisite reach of coordination was evidently not self-accredited on the part of industrial enterprise. Then, again, the field has opened up fully only of late, so that the full measure of the opportunity has not been long standing.

In addition to these considerations, there has been no competitive spur to action. The loss represented in the wasteful consumption of raw coal was not felt by any given industry, since the practice was universal and the cost under this head was a more or less uniform item which was shifted in its entirety to the shoulders of the consuming public.[1] The need for advance was also not generally appreciated, inasmuch as there was plenty of fuel, transportation difficulties had not loomed up, coal products could be purchased from Germany, nitrate could be imported from Chile, and, in general, the whole matter of coal was taken for granted.

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[1] Industrial enterprise has been interested to the extent of bringing multiple production into about half of the coke industry, but here the opportunities are particularly favorable.

[2] As in the case of by-product coking, petroleum refining, etc.

Hence industry had no particular incentive for entering into a new field which, while large, was intangible; moreover industry, under the old order, faced decided limitations in its recognized inability to construct a *proportionated* demand for the whole range of prospective products. On the other hand, the public, which was actually paying the cost of the inadequacy, but under a disguised heading, did not see its concern in the matter, nor was public interest represented by machinery charged with acting on popular behalf; public utilities commissions, the nearest approach to such machinery, were notoriously weak and shallow; the Federal Government, lacking the pressure of public opinion, did not take up the issue. So the course of progress was short-circuited, and the tremendous possibilities in our unrivaled coal resources remain to-day practically untouched. The industrial progress of this country has been sustained by the mining of an ever increasing quantity of coal, until the very bulk of the total has become a critical weakness in this country's industrial life.

Such is the situation. The utilization of coal is extravagantly wasteful from beginning to end, the wastefulness is a matter of uniform practice not subject to improvement through avenues of individual enterprise, and, contrary to general notions, it is the public at large, not industry itself, which stands the loss from the shortcomings in the situation and which is, therefore, primarily concerned in its betterment.

The public is concerned because it pays the bill rendered by present wastefulness and will reap the gain accruing from any progress toward competency. The net advantage will not merely represent the margin of value now lost, but in addition will include the border of advance added by the multiplication of values over those calculable from the standpoint of the present. The total gain can not be expressed in terms of exact figures; indeed, it is in no sense a fixed quantity, but entirely dependent upon the length to which the future carries the matter from its present chaotic stage. But apart from the prospect of future gain, the maintenance of the situation as it now stands is actually costing money. There is no apparent reason why fully coordinated development should not look toward a fairly complete recovery of at least the leading by-products[1] in coal, and this prospect would definitely entail the doubling, if not the trebling, of the fuel efficiency derivable. This means that our present annual coal output could be made to more than double its service, or, accepting the current service requirement as a standard, that less than half the output can do the present work and in addition make heavy contributions to the supply of fertilizers, motor fuel, and chemical products. The aggregate loss, on the basis of this very modest estimate, runs well above a billion dollars a year, or over $10 for each inhabitant of the United States. (See Table, p. 17.) Of such measure is the average man's pecuniary interest in the full utilization of coal.

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[1] In the realm of industry, where wastefulness is a matter of scattering individual practice, the industrial offender pays the direct penalty of loss; but where wastefulness is a matter of uniform practice and is the rule, the whole burden of loss falls upon the consuming public. Ordinarily, the stimulus of competition works automatically to undermine inadequacy and prevent its permanent establishment in uniformity of practice. But if natural obstacles in the path of industrial enterprise render individual activities powerless to proceed in any other than the wasteful direction, nothing operates to prevent the rule of incompetence from becoming a stabilized convention.

Improvement in coal utilization, then, can not be relied upon to come from industrial stimulus alone, but must be brought into effect as the result of public interest in the matter. The means for starting toward this accomplishment are set forth in a separate paper,[2] as lying in the direction of enlarged municipal gas plants, which will handle all the coal needed by the community with the production of solid fuel, gas,[3] and the by-products, ammonia, benzol, and tar.

Through the principle of multiple production, therefore, coal can be forced to render up its full quota of service. This is a new economic force, one scarcely recognized as yet as a principle which may be constructively applied. Yet the principle of multiple production has been gaining headway for years, and by means of it the multiplying needs of man are being met from practically a stationary range of raw materials. The rôle of multiple production is rapidly enlarging; it represents a principle that must come into play more and more to relieve the strain falling upon natural resources and transportation. Through the agency of chemical knowledge it serves to create a divergence of products, each the starting point of a second diverging series. The principle of multiple production is peculiarly applicable to coal and oil; only by the use of this principle, brought into effective action under the guidance of a constructive economic policy, can adequate value be extracted from these power materials.[4]

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[1] Nitrogen, benzol, and tar.

[2] Coal: The resource and its full utilization, Bulletin 102, part 4, of this series.

[3] Or the energy may be separated from the commodity values wholly in the form of gas.

[4] The whole matter of multiple production, a term of broader significance than the more familiar one of by-product production, is discussed in greater detail in Bulletin 102, part 6, of this series. The coming in of multiple production as an economic force will cause a revision in some of the popularly accepted ideas of economics, especially as regards the operation of the "law of supply and demand," as the reactions in the neighborhood of multiple production are different from those occasioned by volume production.

RELATION OF MULTIFLE PRODUCTION AND ELECTRICITY.

The principle of multiple production and the principle of electricity are the two most important economic forces that have come into play during the current industrial order. Nothing since the introduction of steam power can be compared with either of them in significance. Both are radically at variance with the established order; both have a special bearing on the power supply as affording untold possibilities for marked betterment. Neither has won recognition in this field provocative of notable change in the basic conventions of procedure. Here each alike has been ignored, except in so far as its advantages have gained lodgment within the establishments of precedent. Of the two electricity has made the greater headway; multiple production has not yet found an opening outside the confines of the coke industry and has succeeded in preempting only half of that field.[1] Neither electricity nor by-product coal utilization has entirely been neglected, but the real possibilities for the common good so bountifully contained in each have never been cultivated in the least.

In the realm of power these two great agencies of economic advance are exactly complementary. Together they present a solution for the transportation aspects of the power problem, not to mention their bearing in other regards. The principle of multiple production enables the full utilization of the whole range of values transported in the form of coal. Electricity makes it possible to transmit *energy* where energy alone is required and thus frees the ordinary channels of transportation of a needless burden of bulk haulage. The first would determine the amount of coal needed and insure the adequate employment of that amount; the second would make it unnecessary for the railways to haul more than the amount thus determined. The outcome merely waits upon the application of these two economic forces in effective coordination.

POWER RESOURCES AND ADVANCE ELIMINATION OF WEIGHT.[2]

Before the advent of electricity energy was inseparable from a material expression, and the economics of power usage grew up under the exigencies of this dependence, as illustrated in the distributive use of coal. But now a command of the electrical principle makes it possible to deal with energy freed from substance. This not only concerns coal by providing the means for extracting the energy at the point of production, instead of at the many points of use, to the gain of efficiency and the saving of transportation; but it applies also to water power, a resource hitherto fallen into disuse because of its inability to cope with coal, but reintroduced by electricity upon more advantageous terms, to the practical gain of a new energy resource. In spite of the fact that electricity has been in common and growing use in this country for many years, it has effected practically no change in the basic conventions of coal usage and has led to the development of a small fraction merely of the available water power.

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[1] The gas industry weighs but lightly in this connection, as this activity consumes only about 1 per cent of the bituminous coal production, and in this field multiple production has scarcely started. The principle of multiple production, however, spells the future—the only future, but that a great one—for the gas industry.

[2] Oil is left out of consideration, for the present purpose, as involving a highly specialized field which can not be gone into here without an unwarranted digression; besides, this matter is treated in detail in Bulletin 102, part 6, of this series. Counting off the use of gasoline and other light oils for automotive purposes (a field of power application not ordinarily considered in connection with the problem of industrial power), there is a formidable and growing quantity of fuel oil that is devoted to steam raising; large areas of the country, indeed, not within easy reach of coal fields, are served by fuel oil to the almost complete exclusion of coal, while even within the coal territory fuel oil has replaced coal to some extent. But the character of the resource indicates that the growth of fuel-oil employment is of a mushroom order; with a capacity for infinitely greater refinement of function, its use for the brute force of industrial power is a perversion which can have no permanent place in the category of progress. Though transiently a competitor to coal and water power, oil is fundamentally a supplementary resource; its degree of overlap now represents the measure of its perversion.

Since electricity has rehabilitated water power, thus making available two energy resources where there was only one before, it is desirable to determine the resource status of water power as compared point for point with coal power, for the two are coming, of necessity, into competition, and unless water power in its new habiliment can stand on a reasonably equal footing the outcome of the competition is bound to fall in favor of coal, as occurred before when steam power drove hydraulic power to the wall. In which event water power, in spite of its ethical advantages, would have no special signficance for the present.

In respect to the size of the resource reinstated by electricity, there can be no fault to find. Efforts to determine its magnitude have led to estimates placing the possibilities of hydroelectric development in the neighborhood of 200 million horsepower, of which some 50 million is capable of use without special provisions for storage.[1] Expressed in another manner, the water power of the United States, converted to electrical energy, is more than capable of turning every industrial wheel and illuminating every street and building in the entire country. Also the resource is country-wide in distribution. (See fig. 1.) The apportionment amongst the various sections is by no means even, but the supply is more widely and equably spread than is the case with the coal fields; and the regions distant from the sources of coal are all bountifully favored with water power. Thus New England, the South Atlantic States, the Southwest, and the Pacific slope, together embracing over half of the potential water power of the country, are all practically without coal and bear testimony to this complementary distribution of power resources. (See Table 2.) This balanced occurrence has considerable bearing upon the welfare of the Nation, as treated in some length under "The nationalization of industrial opportunity.[1]

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[1] The discrepancies in the various attempts to inventory the water-power resources of this country are due to several qualifying factors, notably that of storage. Since the demand for power is commonly uniform the year round, the capacity of a given site for sustained effort is determined by the period of minimum flow. Accordingly, storage provisions doubling the flow merely during such periods will double the year-round capacity.

TABLE 2.—*Distribution of water power in sections lacking in coal.*

[Figures approximate and given in round numbers.]

	Potential water power (percentage of total in United States).	Unmined coal (percentage of total reserve).	Unmined oil (percentage of total reserve).
New England States (Maine, Vermont, New Hampshire, Massachusetts, Rhode Island, Connecticut).	3 per cent	None	None.
South Atlantic States (Delaware, Maryland, Virginia, South Carolina, Georgia, Florida).	6 per cent	1 per cent (practically all in Virginia and Maryland).	None.
Southwestern States (Arizona, New Mexico, Texas, Oklahoma, Arkansas, Louisiana).	6 per cent	4 per cent (mostly in Oklahoma and Texas).	52 per cent.[a]
Pacific States (California, Oregon, Washington).	43 per cent	2 per cent (mostly in Washington).	31 per cent.
All other States	42 per cent	93 per cent	17 per cent.

[a] Includes Kansas.

But in spite of the advantages of size and wide distribution enjoyed by water power, this resource has not been able thus far to enter into serious competition with coal. Only some 10 per cent of the total expansion in power consumption in recent years has been in the direction of water power. The present production of hydroelectricity in the United States represents roughly the equivalent of 40,000,000 tons of coal, whereas nearly 400,000,000 tons of coal goes into the production of steam power and carboelectric power.[2] The water power developed to date is around 10 per cent of that readily available; scarcely 3 per cent of the total open to development under elaborate arrangements for storage.[3] (See fig. 2.)

The favorite explanation for this laggard growth on the side of water power ascribes the whole trouble, either directly or inferentially, to the handicaps imposed upon private initiative by the inadequacies of Federal legislation. The facts do not bear out such conclusion further than to accredit this factor with contributive importance. Federal permits are requisite to the development of 75 to 80 per cent of the potential water power of the country, the balance being accessible so far as Federal permits go. About 4 per cent of the restricted portion and about 25 per cent of the part outside Federal surveillance have been actually put to work. The discrepancy of 21 per cent between the two is impressive, but even granted that this is attributable wholly to Federal interference, which is not the case,[1] it will be seen that the nondevelopment of three-quarters of the potential water power of the country remains to be accounted for on another basis. In other words, the quality of Federal legislation, even under sweeping concessions to its untoward effect, provides but a minor element in the complete explanation.[2]

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[1] See pp. 38–42.

[2] The term *carboelectricity* is self-explanatory; it is used to cover electricity generated from the carbon fuels, such as coal. It stands in contrast to hydroelectricity, electricity generated from water power.

[3] Estimates of this kind are provisional only, for the amounts of the "readily available" and "total" are not accurately known nor definite.

The specific obstructions to the unfoldment of water power will be looked at later, but back of these instrumentalities is a fundamental economic setting which is essential to the view. The main features of this background are two in number. One is concerned with a relation between the power resources; the other, with the force of convention in respect to power usage.

In the first place, coal and oil have been so bountiful in this country that only the richest portions of these resources are worked; a project contemplating the development of a water-power site faces this situation.[3] It is evident that the cream of the water-power re-

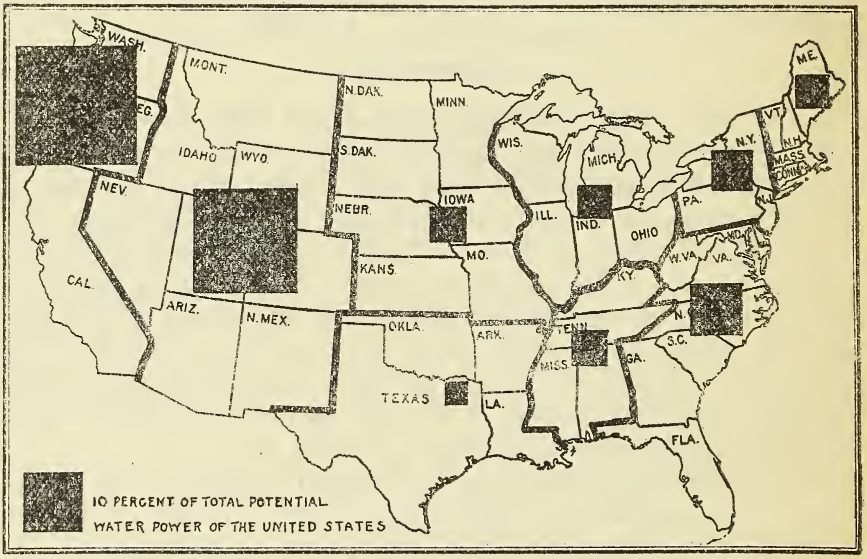

Fig. 1.—The distribution of the water-power resources of the United States.

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[1] The water-power rights subject to Federal jurisdiction are largely located in regions of the West remote from industrial centers where they are not currently wanted anyway.

[2] Of course, the whole default may be attributed to the Government's *lack of action*, but the total effect of ill-advised legislation, while significant, has been exaggerated.

[3] The fuel resources of the United States have been mined on such an extravagantly uneconomical basis of opportunism that for the time being a superabundance of coal and oil has been maintained on the market. It may sound as if one were making light of the facts to speak of there being an overproduction of coal and oil at a time when everyone is meeting on every hand a shortage of these basic materials. Yet it is well within conservative figures to assert, even without reference to water-power potentialities, that this country has long produced more than double the amount of coal and oil really needed under proper arrangements; and, of necessity, the surplus has had to be consumed in the form of waste. Overproduction leads to waste; waste leads to overproduction; and so the circle goes on unbroken. With no pressing necessity for introducing economies in the use of coal and oil, there was still less of urgency to call the more basic economy of water power into play.

source has demonstrated its capacity to compete with the cream of the fuel resources, and it is a fair assumption that the balance is reasonably even in this area of rich values. But most of the cream, aside from that withheld by Federal restrictions and assiduously sought after by special interests with a taste for such matters, has been skimmed from water power, while it has not yet been exhausted from coal and oil; and the average of hydroelectric power, under present conditions, can not compete against the residuum of cream now being assiduously removed from the other two.[1] But the course of preferential skimming will tend to equal matters up, and a steady increase in the significance of the water-power resource is to be anticipated.

In the second place, and viewed from the standpoint of the large consumer of power, the use of fuel is the established convention for covering the needs for power. Where steam power is wanted, fuel of course must be used. But even where electricity is re-

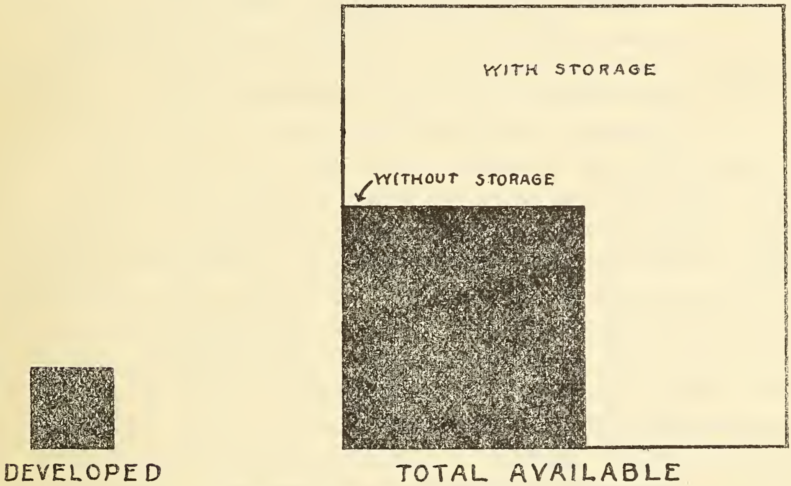

Fig. 2.—Chart showing the developed water power of the United States contrasted with the total resource.

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[1] It is evident, of course, that considerable coal and oil are being sacrificed for the sake of giving water power a better resource standing. This, in a national sense, is unfortunate; for the coal supply, while great, is not unlimited, and its needless use involves the loss of coal products, the true importance of which in a few years are bound to be recognized; while the petroleum reserve is already on the verge of exhaustion. The fuel resources are fixed in quantity and are in the nature of capital which does not draw interest; water power, on the other hand, may be compared to an annuity, the annual increments of which lapse if not currently used. Hence, as a concession to convenience and in the flush of resource wealth, this country has run into the economic impropriety of drawing upon its energy capital while neglectful of its energy annuity. While this, of course, will afford an unpleasant contemplation to the next generation and may even affect the younger members of the present, at the same time it is recognized that such a consideration has scant practical weight in favor of bettering the situation as standing now.

quired, fuel is usually the most convenient source. For purposes of generating electricity the primary power is ready at hand in the case of operations already established on a steam-power basis, while for the service of expanded or newly projected operations the simple expedient of enlarging or at most erecting a steam-power plant is all that is necessary. In either case the first cost is low, and the chief element in outlay is the expenditures under the heading of fuel purchases, which follow along steadily, but are distributed over the subsequent years of operation. The current proceeds from these operations are counted on to care for this train of expense; hence, from a pecuniary standpoint on the part of a given industrial activity, there is no occasion for advance effort in capitalization under this head beyond the amount called for in connection with the subordinate item of cost for the erection and equipment of a steam-power plant. In the case of hydroelectric development, on the contrary, the conditions are reversed, and the whole weight of emphasis falls at the outset on the initial cost of power-site development. The running cost of hydroelectric power consists mainly in the single item of interest money on the capital represented in the initial outlay.[1] An analogous condition would obtain on the side of coal-generated electricity if a given enterprise were called upon to provide an adequately equipped coal mine in addition to the power plant itself. In the one instance, as matters now stand, the coal mines are already established in lavish numbers and do not enter into investment calculations; in the other, the power sites, with choice exceptions, still lie fallow and have yet to be developed if they are to be used. This is the situation facing any given industrial enterprise, however large, in respect to establishing its source of power. For the hydroelectric alternative to be chosen, it must present more than equal advantage. Indeed, it must be decidedly preferable, for projects in process of formulation or expansion are apt to find their capitalizing ability pretty fully exercised without taking on the development of any special source of power, whether in the nature of a coal mine or a water-power site. Hence, in the process of natural selection exerted by business enterprise, water power is usually set aside as presenting claims inferior to coal.

This holds true not merely for manufacturing projects but for purely electric-power projects as well. No exception is found even in these common instances of municipal electric-power supply, where the bulk of the consumption is on the basis of pay the price or do without. What is the use, in these cases, of undertaking the tremendous extra effort connected with developing a special water-power source, even granted an ultimate saving in cost? A public-utilities commission would in all likelihood force a corresponding reduction in price, and all the effort would come to nothing really worth while, since these projects are in the nature of public-service corporations.[1] The public at large can be relied upon to pay any price conventionally established just so long as the actual cost of production is sufficiently high to prevent the rate from being too extortionate; hence, no one gains by lowering the cost of production—except the public, which goes, therefore, to no account. A special price may even be quoted to industrial users to discourage the larger interests from generating their own electric power, since they have a choice in this matter which the public does not enjoy. Thus the river that flows through the town has the beauty of its course unsullied by commercialism. Instead, a trolley park, with merry-go-rounds, dancing pavilions, loop-the-loops, and the like, occupy the power site. With its art and enterprise thus catered to, American municipal life in plentiful instances, not excepting that of the Capital city itself, is disposed to rest content.

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[1] See p. 30.

Thus industrially and civically alike the electric-power situation is stagnant, caught in a backwater of convenience, with the course of progress blocked by the obstacles of initial cost. But it is not hydroelectricity alone which has its progress thus obstructed. Its case is conspicuous because the resource itself is largely cut off from employment and advertises the inadequacies of the situation broadcast over the landscape. The shortcomings with reference to carboelectricity are not so obtrusive and hence not so notorious; they are not heralded openly by actual disuse, but are cloaked instead under conventional misapplication. Thus commonly as much as a fourth of the coal-fired power employed in centers of population has its energy applied in the form of electricity. Yet, with the rarest exceptions,[2] this energy is transported to the centers of use in the form of coal and there the electricity is generated in steam-power plants. Electric-power usage has merely been appended to the established structure of steam-power practice, with the result that the employment of power has been greatly facilitated, to the further aggravation of the broad problem of transportation. Thus far the very force that has the capacity to correct the transportation evil has merely served to accentuate it. By virtue of electricity, more power is consumed, more raw materials are required, more goods are produced, more coal is freighted.

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[1] A designation not altogether clearly understood. It is sometimes construed as implying corporations serving the public instead of being served by the public. The former meaning is not justified by practice.

[2] The most significant exception is a power plant near Lansford, Pennsylvania, which was placed at the coal source for the express purpose of serving a distant patronage, its ultimate goal, indeed, being Philadelphia and New York. Of course, first and last, there are numerous steam-electric plants in the coal regions, but with very few exceptions they are present because of a local demand for electricity, not by virtue of the presence of coal; in the aggregate, therefore, they scarcely temper the transportation burden in the coal country itself and have no effect at all upon it outside.

The distributive generation of electric power was natural enough and the only practical procedure so long as the use of electricity was small. But that time has passed. Electricity is now a commodity in everyday use, with a large and steadily growing aggregate demand; to adhere to the original practice bespeaks obsolescence. Such escape as has been made from the confines of stagnation has been almost wholly in the direction of hydroelectricity. So, in spite of the great amount of talk and publicity that centers around the water-power issue, there is more evidence of basic progress on this score than may be found on the side of coal power. All that may be fairly said in dispraise of the progress of this country in respect to water-power is likewise true as regards coal power. In fact, this country does not face a water-power problem as such; the issue is more broadly a power problem, of which water power constitutes only one important segment.

Objection may arise at this point that a systematic generation of electricity in coal fields is prevented by technological difficulties in the way of long-distance transmission of power to the points of use. It is true that there are many open problems in long-distance service of this kind, but these are by no means insuperable; yet, granting them full weight and considering merely what has been already accomplished in connection with hydroelectric transmission, we find that transmission lines 100 miles in length are common, while those up to 250 miles in length are known and regarded as practical. If we accept say a 200-mile radius as a present standard, and consider the distribution of the coal fields of the country in relation to the centers of population, we find that circles may be drawn around centers of coal production which will embrace a considerable area and much of the industrial territory of the country. Thus on the basis of present technical attainments alone, with no allowance for improvements under way, a large share of the current power demand could be supplied directly over wires from the coal fields.

Such a change in practice would operate to the relief of transportation and on this score contribute a country-wide advantage. But it would also create special industrial opportunities which would fall only within the reaches of the transmission systems. Hence to plan a comprehensive development of the areas in proximity to coal fields would be to emphasize and accentuate the advantages of environment which are already proving hurtful to the economic growth of the country as a whole.[1] The economic gain that would come to outlying sections through the general betterment of transportation would certainly be more than offset by the economic losses resulting from the increased disparity in power supply. There is no occasion, however, to confine attention to coal-field developments without regard to the distribution of water-power resources, which, as already noted, bulk largest in the regions lacking in coal. Rather than to single out the coal regions for favor, it would be preferable to take the opposite course, leaving the near-by sections to be served by freight-hauled coal and relieving the longer hauls by promoting the systematic development of outlying water-power sites, and thereby not only help transportation to better advantage but conserve the natural resources involved and diffuse industrial opportunity as well. But fortunately the two lines of action are not alternates. On the contrary, they enmesh in a singularly perfect manner and lead to a common end. In this light it is important to review more specifically the obstacles which have hindered water power and all but excluded coal power from assuming the complementary rôles to which they are admirably adapted by virtue of their natural dispositions.

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[1] See The nationalization of industrial opportunity, pp. 38–42.

Of the two, water power may be looked at first, because it is the more conspicuous in its failure and in extenuation offers reasons complicated by a greater scope of variety. For the most part these qualifications have already been examined, and, besides, to a great degree, they are either self-explanatory or, at least, have been given sufficient publicity of discussion to be more or less common property. Accordingly, in the interest of brevity, they may be listed with a few comments only rather than gone into at length.

1. *Adverse legislation.*—Here the situation has been clouded by various issues of Federal, State, and individual rights, covering not only the immediate subject of power but sundry other uses, such as stream navigation, likely to be interfered with. In view of these complications, legislation has characteristically been framed with an eye toward legalistic ends rather than in the direction of a genuinely constructive economic outcome.

2. *Public sentiment.*—There is a general feeling, natural enough in the strength of its hold, that in the beauty of the country's rivers, with their rapids and waterfalls, adheres a certain nobility of function whose grandeur is the common birthright of all. The surrender of this heritage to the interests of commercialized service is a line of conduct not likely to meet with public approval. Whatever of actual substance in the way of purpose is to be recognized in the fabric of legalism, as noted under the previous caption, has been contributed largely in response to this attitude of public sentiment. The attitude has unquestionable justification and must be reckoned with. Those on the one side who would have it ignored are as far wrong in the solution of the water-power issue as those who would give it unqualified heed. Yet the principle is universally recognized that the inter-

ests of beauty must give place to pressing needs of utility. This consideration alone would not give rise to disfavor in regard to water-power development. The source of disapprobation lies in the lack of vivid appreciation as to the matter of need, coupled with the attendant imputation of surrender to vested interests. Accordingly the water-power situation can not be satisfactorily cleared up until the need for the systematic development of this resource is firmly established; until freight congestions, fireless homes, foodstuff costs, and other intimately personal issues are seen to be genuinely involved; until the opportunity for the restrictive furtherance of special interests, financial or sectional, has been eliminated. Until these conditions have been met, attempts to promote the development of our water-power resources are bound to result in ineffectual compromises.

3. *Cost.*—A hydroelectric station, once established, is largely self-contained and automatic in operation. There are no periodic items of cost for fuel, for its freightage, haulage, handling, and the like, such as associate themselves with the operation of a steam-power plant. So, apart from such incidentals as administration, insurance, taxes, and depreciation, which together bulk small, practically the whole burden of gross operating expense is that assumed at the outset in the guise of initial cost and perpetuated in the form of interest money.[1]

Thus the cost of money, displaying itself in bond interest, is the determining factor in the cost of hydroelectric power precisely as the price of fuel, with its accompaniment of expense, determines the cost of steam power. The cost of money in this country, on a strictly commercial basis, is high. The prevailing rate of interest demanded of water-power developments is around 7 or 8 per cent, which, with discounts taken into consideration, normally means a demand amounting to 9 or 10 per cent on the working proposition. Estimate after estimate the country over has gone to show that only the

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[1] A unit analysis of the gross operating expenses of a typical steam-electric and hydroelectric station of the same capacity (20,000 horsepower; annual load factor, 50 per cent; coal, at $3.25 per ton delivered) is given as follows by Gano Dunn, The water-power situation including its financial aspects, Proc. Amer. Inst. Electr. Eng., May, 1916, p. 585:

	Steam station (per cent of total gross operating expenses).	Hydroelectric station (per cent of total gross operating expenses).
Administration	4.0	4.0
Ordinary operating expenses (except coal)	10.6	4.8
Coal	48.9	....
Taxes and Insurance	6.7	2.8
Depreciation	10.8	11.0
Bond interest	19.0	77.4
Total	100.0	100.0

water-power site especially favored by natural advantage is susceptible to development under these conditions in competition with the prevailing cost of steam power. These favored examples also frequently provide a bone of contention over which conflicting interests raise a great to do, tending to create the impression that the water-power resources of the country constitute a tremendous asset whose possibilities are being arbitrarily withheld from their normal course of unfoldment. Nothing could be much further from the truth. With the exception of the few conspicuous instances that serve as a stimulus in keeping the question alive, no particular significance attaches to the country's undeveloped water power under existing conditions of finance, or will, until either these conditions have been lived down or steps have been taken to better them. The former represents a tendency which left to itself is not likely to yield anything of consequence for years to come. Nor is there any room for hope in technological advance. The issue of cost is a matter which, like the legal and sentimental obstacles just outlined, must be overcome, and the only way in sight lies through arrangements which will impart a degree of stability to water-power securities such that they will receive the benefit of a reduced rate of interest. This phase of the subject will receive further attention later on.

Thus the influences holding back water-power development are of a threefold order. These do not operate separately, but in conjunction with one another. Water-power development stands in need of special consideration; instead, it meets with special opposition. There is none to work in its behalf except those with special objects in view, and the recognition of this quality in their efforts has gone to establish opposition. The contention in this wise has grown to be organized on both sides, with each alike oblivious to the real community of interests involved and legislative action caught fast in an entanglement of compromise. In all three respects the situation is in a deadlock and the likeliest chance of a break toward progress lies in the entry of a new standard in the field, a standard under which the rights and best interests of all concerned can have the assurance of fitting recognition.

The carboelectric issue, on the other hand, is far less advanced and correspondingly less complicated. It has scarcely progressed beyond the general setting of inertia which characterizes the failure to locate power stations at the source of fuel supply and still determines their establishment distributively at the points of use. There have been no special interests involved to stimulate any particular activity otherwise; there has in consequence arisen no basis for the provocation of organized opposition or legal byplay. The hydroelectric issue has been seen to stand in need of a new standard; the issue of carboelectricity has not even been popularly recognized. Ordinarily, under such conditions, sporadic activities appear over the even surface of apathy as precursors to an organized effort to follow. In this case there has been an obstacle to check such sporadic beginnings. It is the obstacle of initial cost expressing itself in the matter of electric transmission lines. In meeting this aspect of the situation we come face to face with the third element of our major theme of discussion—the facilities best suited to advantageous transportation.

FACILITIES OF TRANSPORTATION AS APPLIED TO POWER.

We have seen from our discussion thus far that full utilization of the energy materials in distributive use involves the constructive application of the principle of multiple production, and that the advance elimination of weight is concerned with the generation of electric power in centralized relationship to coal fields and water-power sites.[1] The nature of these issues and the problem they afford have been explored, and it now remains to trace the issue concerned with the provision of adequate facilities for the transportation of energy in concentrated form.

Energy is practically the only natural resource product susceptible of concentration which is shipped broadcast in the crude condition. The dictates of demand, it is true, still call for a large proportion of the supply in the crude state, and to this extent concentration in advance is obviously impracticable.[2] But the order of requirement is changing rapidly, and even now over one-fourth of the call is for the concentrated product—electricity. Yet, as we have seen, there has been no progressive change in practice to correspond. It is as if our gold supply were shipped in the crude state of its native occurrence for concentration at the market centers instead of at the mine; for whereas the degree of material concentration effected on behalf of gold is considerably over 99 per cent, the attainment possible on the side of energy is a full 100 per cent. There is just one important difference between the two instances. Refined gold is adapted to haulage by the conventional means of transportation at hand, fully as much so, indeed, as the ore from which it is derived. But refined energy is not. It can not be loaded in freight cars or done up in express packages. The alternatives lie in providing special facilities of transportation or else hauling the crude material in all its excess bulk for concentration at the points of use, and the choice in practice has uniformly fallen in favor of the second procedure.

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[1] It is only as applied to organized transportation that the issues of advance concentration and multiple production are strictly complementary. The recovery of by-products is just as feasible and desirable in connection with carboelectric superpower stations centralized in respect to coal sources as it is in connection with any set of operations centralized with reference to consumptive demand, as, for example, in the case of gas manufacture.

[2] Except in so far, of course, as a change in the supply would modify the demand.

The reason for this uniformity is obvious. It is cheaper for the user of energy to rely upon the transportation facilities already at hand, employing them in the movement of the crude bulky material, than to provide himself with special facilities for the transmission of the refined electric derivative. But it does not follow, to be sure, that because the procedure so uniformly followed is individually cheaper, this course is economically preferable. In the absence of railway facilities, for example, it would be decidedly cheaper for the individual consumer to haul his coal from the nearest mine by truck than to build a railway line for the purpose. Yet no one would think of arguing in this case that reliance upon truck haulage is preferable to the opportunities that would be afforded by railway transportation. The issue between electric transmission and railway haulage is precisely similar.

The provision of special facilities of transportation finds its justification in the magnitude of the service to be rendered. Were the item of haulage under view small in size or restricted in locality the whole matter need not come up as a broad problem. But the haulage of power in material form amounts to nearly a half billion tons and covers the country. There is no default, then, on the side of magnitude. Special facilities, too, have been provided for oil, the power material next in importance to coal. To serve the ends of this large resource a network of pipe lines, thousands of miles in aggregate length, are spread over half the country. In this case, however, crude oil is not in the nature of a general utility, but serves a specialized industrial demand centered in refineries. In consequence, pipe-line transportation found its creation and nourishment at the hands of the large private interests at stake. For electric power, on the contrary, there was no such activating interest. Though bulking large, it enjoyed a diverging distributive use quite the opposite of the convergent refinery consumption of crude oil. Moreover, the railroads were already established in coal fields when electricity came on the scene; their presence, therefore, offered scant encouragement to the growth of a more modern type of common carrier. On the contrary, it may be surmised that the whole matter may have been arbitrarily held back by the pecuniary disadvantage that would accrue to the established undertaking in event of change. Indeed, it may well be that this consideration has not been without weight in retarding the electrification of the railway lines themselves. A given railroad, under conditions of active competition, could scarcely be expected to take the lead in giving up such a lucrative item as the transportation of coal. It thus appears that such interests as already occupied the field were inclined to oppose the provision of special facilities for the transportation of energy, while in respect to oil the interests concerned in advancing its transportation were sufficiently strong and organized to overcome the factors inhibiting the establishment of the modern pipe line. Hence the energy needs of the country are now served by two carrier systems instead of three.

A special type of transportation equipment in the way of electrical transmission lines is urgently needed to serve the energy requirements of this country, but these special facilities may be advantageously established only on the basis of a common carrier. In close analogy to the railroads, though in contradistinction to oil pipe lines, the service to be rendered is strictly distributive and of a public-service order; hence competition here is out of place to precisely the extent that it is inexpedient in the case of the railways. The railroads of this country wrought havoc with industrial life until the element of special-interest preference was eliminated and the whole system was placed on a common-carrier, public-utility basis. We may profit in this matter by that experience, and arrange to skip the period of adjustment that proved so costly and disastrous in connection with railway development. The railroads, therefore, provide a warning example from which may be determined the status that should be accorded the new development. Hauling coal is a problem of transportation; hauling energy in the form of electricity involves the same range of principles but requires merely a different set of physical means. In point of fact, the whole advancement contemplated is but a further refinement in transportation equipment, just as the modern steel gondola[1] is a refinement of the old-fashioned coal car.

The railroads themselves have a prime interest in this matter of establishing more facile means for the transportation of energy. Not only are they the chief haulers of energy in bulky form, but they likewise constitute the chief single consumer of this material energy which burdens their lines. The railroads burn approximately a fourth of all the coal produced in this country,[2] this item along representing at least a tenth of their total operating expense.[3] Thus an improvement in energy transportation would not only relieve the railways from a needless burden of bulk haulage, but would at the same time benefit otherwise their operations by giving an impetus to railway electrification, with attendant gain in freight movements by nature of the greater freight capacity accruing to electrified systems.[1] Thus, on every count, the matter resolves itself into an inseparable part of the transportation problem, and from this coalescence there is no escape.[2]

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[1] A self-dumping car now in common use for hauling coal.

[2] In 1915 the railways of the country used 24 per cent of the total output, or 28 per cent of the bituminous production (C. E. Lesher, Coal, Mineral Resources of the United States for 1915, United States Geological Survey, pt. 2, 1917, p. 473). This has nothing to say of the fact that about one-eight of the petroleum output is consumed by railways.

[3] A determination of 11.05 per cent is given as an average of all the railroads in the United States States having operating revenues greater than $100.000 in the year, by L. B. Stillwell, Relation of water power to transportation, Proc. Amer. Inst. Electr. Eng., May, 1916, p. 562.

CORRELATION OF WATER POWER AND COAL POWER.

Bringing together the two issues of water power and coal power, which we have followed thus far in parallel considerations, we find that the causes which have retarded the development of hydroelectricity and prevented the establishment of carboelectric power stations at coal mines are broadly similar. In the case of water power, the failure is traceable to (*a*) initial cost and (*b*) a deadlocked issue between public and private interests; while, with coal, the element of initial cost has been almost equally effective, with a lack of interest,[3] instead of discordant interests, acting as the contributory factor. The provision of suitable transportation will clear up the two retarding influences in both cases.

In the first place, the establishment of a common-carrier system of electric transmission lines on a public utility basis will nearly halve the interest rate now demanded of projects having to do with electrical developments. We have for this assurance the example of the railways themselves, which have long been accustomed to procure capital at rates of 5 to 6 per cent. The system under view could be given more stability than the railways have formerly enjoyed, to the gain, perhaps, of even better interest rates than may be calculated from the unqualified analogy. Not only would this stability be inherent in the transmission line development itself, but would reflect a similar measure of soundness upon the projects concerned with the development of power sites and the establishment of power plants, so that the field of power operations in its entirety would benefit. The recognition of public backing would transfer the whole matter from the type of investment sponsored by the professional promotor to the realm of securities represented by bonds of a substantial and conservative standing. And since the cost of money is the major expense attached to the developments, the reduction of this factor would reflect in increased proportion in the lowered price of electric power.[1]

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[1] The increase in freight capacity that accrues from electrification, with its accessory automatic devices that permit an almost solid stream of freight cars, is startlingly great in view of freight congestions under present arrangements. With proper terminal facilities and electrification, it is safe to say that the freight capacity of a system could be multiplied by a considerable figure. It has been recently estimated, for example that inland transportation in England attains a capacity efficiency of scarcely 10 per cent. It has frequently been noticed in the United States as to the anomoly of hauling coal halfway across the continent to lift a train across the Continental Divide, when the topography of the divide is ready to provide for this purpose hydroelectric energy, which itself is susceptible to partial recovery on the down slope by means of regenerative braking. In this connection, the pioneer work of the Chicago, Milwaukee & St. Paul Railway is deserving of the highest commendation for its constructive significance.

[2] It is commonly recognized that one of the weakest features in the industrial development of the United States is the overaccentuated responsibility now falling upon the railways; any measure tending to lighten this weight obviously strikes at the roots of a very fundamental and important issue. While the consideration may be a gratuitous digression in this place, a plan for adequate inland transportation in this country is conceived to embrace (*a*) airplane service for special mail and for passengers restricted in time; (*b*) motor-truck service for short-haul freight and for the service of farming districts in coordination with parcel-post deliveries; (*c*) railway service for normal freight and passenger accommodations; (*d*) trunk-line, deep waterway haulage for slow-moving and bulky freight; and (*e*) transmission lines for the delivery of electrical energy from the coal fields and water-power sites.

[3] Such private interests as might have had a concern in the matter (as the railways) were rather inclined to cast their influence on the side of inaction in this respect; while the public interest, as usual, had no eyes with which to see their concern; in result, a state of outward apathy surrounded the issue.

In the second place, a special common-carrier system under public oversight would serve to give the proper temper to the apprehension of the public in respect to surrendering what is now conceived to be its natural rights, thus breaking the deadlocked issue that has so long contributed to the sluggishness of hydroelectric developments; while the apathy surrounding the matter of coal-field generation of electric power would be replaced by conditions making for the profitable establishment of this activity. The public, seeing its interests properly safeguarded, can be counted on for sympathetic support of the movement; while industrial interests in general, being in the business of manufacturing commodities rather than energy, will find it natural to favor any action that would facilitate the supply of energy—an accessory to their operations—just as they are keenly interested in any constructive measures that would be likely to ease off the labor problem.

The experience of this country has shown that the conduct of the common-carrier systems must be subject to public oversight.[2] At the same time, it has been amply demonstrated that, for the sake of safeguarding private initiative and business enterprise, this oversight should be called into play as slightly as conditions permit.[3] Applying these concepts to the proposition in hand, we reach the conclusion that while it is necessary that a system of electric transmission lines should be of a common-carrier, public-utility order, for which the railways provide a pattern;[1] the realm of power production offers great leeway for the upgrowth of coordinated, but separately constituted activities, thus stimulating initiative and encouraging business enterprise far beyond their present attainments in this field. In this connection, it is worthy of emphasis that such restrictions as may be inherently necessary in correlating the whole fringe of attendant activities with the central enterprise will be overwhelmingly offset by the tremendous opportunities created by the unfoldment.

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[1] It should be mentioned that in many instances the development of water-power sites involves the provision of facilities for navigation and irrigation. These attendant activities would be in the nature of by-products, so to speak, over the gain to be derived on the score of power, and as such they should weigh in outlay calculations as joint sharers in the expense apportionment. The provision of a lower money cost for water-power development, therefore, would reflect advantages over a wider scope than is embraced even in the broad item of power usage.

[2] See pp. 12–15.

[3] While there can be, of course, no universal agreement to premises of this kind, these two conditions are believed to represent fairly the common sense of the country in this matter. They certainly involve no violent assumptions, for both for some time have been guiding influences in the destiny of the Nation.

This type of development will place water power and coal on an equal footing. In regions where only one is present, that, of course, will alone produce. But in regions where both are on hand, the one rendering the cheaper service will come into play through a process of natural, unhampered selection. Thus the common carrier will coordinate the two resources, so long estranged, and lead to their complementary and balanced development. Adequate transportation has always been necessary to the development of resources; it is a trite commonplace that no region, however rich, can become of consequence until served by proper carriage. This is no less true with energy. Given suitable transportation and our energy supply is assured.[2]

The final status of a common-carrier system for the transmission of energy can not be determined at this moment. The entire problem of transportation is in course of flux, and the special issue of power must be cast into the cauldron in which the railway matter is boiling. As the railways emerge, so should power. But with no inclination toward voicing a decision in the matter, it may be anticipated that a special transportation service for power, to fulfill its proper function, will have to be either (1) an integrated activity, privately financed, but under public oversight on the basis of a common carrier, and comparable to a railway company; or (2) if still closer Federal oversight be desirable, a close corporation, in which the Government holds the stock, bearing some analogy to the activities now being carried on in behalf of the country by the Food Administration and the Emergency Fleet Corporation.

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[1] Owing to the relative shortness of transmission radius (up to about 200 miles under present practice), conditions might arise in certain localities in which the authority vested in the Federal Government under the head of interstate commerce might prove more restricted than in the case of the railways. These and similar difficulties will no doubt arise, and objections to the whole conception may be raised on this score, but technical niceties and equivocations are being cast aside right and left in response to the claims of progress, and in this respect nothing of an unsurmountable nature can be discerned ahead.

[2] Taking a broad view ahead, we are confronted with the fact that the whole forward sweep of electrical development is dependent upon a supply of copper, or some such metal of ready conductivity. The copper supply of the world has come under close observation during the course of the present war and there has resulted no special confidence in the bountifulness of supply for the future. As is well known, copper mining has already been reduced to the expedient of working a lean type of disseminated deposit by large-scale methods of operation, and a large part of the world's output is so derived. In view of the importance of the property of conductivity, the whole future of transportation would seem here to enmesh with mineral resource efficiency in respect to copper and with electrochemical advance in respect to developing supplies of other conductors.

But whatever the outcome of the railway issue—or, more broadly, the transportation issue, from which the power problem is inseparate—this country need not wait upon the eventuality before taking action. Just as the railroads are not idle during the period pending their final disposition, so the matter of energy transmission should not be held in abeyance until the question of control is settled. On the contrary, the establishment of such a project would require a preliminary period of planning and investigation, including a survey of the coal and water-power resources of the country with reference to the demand for power, and there is no apparent reason why this initial activity could not be engaged in at once. In view of the importance of the issue, this is not a matter to be referred to one side as an incidental piece of work, but belongs properly as a feature in the emergency activities of the day.

NATIONALIZATION OF INDUSTRIAL OPPORTUNITY.

Power and raw materials constitute the foundations of industry. Capital, labor, markets, and other elements enter into the structure, but they do not lie at the base. Neither power resources nor raw materials are uniformly available; both tend to be provincial in occurrence; but since industrial power is dominantly drawn from coal, while raw materials are derived from a thousand sources of organic and mineral origin, the aggregate availability is far more restricted in the case of coal. In other words, any given section of the country is almost invariably provided with raw material of some kind, while under the present régime only those sections contiguous to rich coal fields are amply provided with power.[1] The geographical and political consequences of the localized occurrence of coal and of concentrated types of raw materials[2] are obvious and well known. The inequalities of opportunity conditioned by these matters have always been bones of contention, from the aboriginal strife over deposits of salt and flint down to the action which resulted in the conquest of an iron-bearing province and contributed prominently to the epoch-making conflict now raging.

Discord from this source is as old as human history and nations have evolved with the placement of their boundaries strongly influenced by concentrations of resource opportunity. The North American Continent, however, provides a notable exception to the rule. Its vast area was explored and appropriated before its resource potentialities were recognized, and hence its various sections came to be unified into a few nationalities on the strength of social bonds, which, with one or two exceptions, have nowhere been dissevered by subsequent economic influences. Thus the United States is a nation of many parts bound together by social unity, but separated by a divergence of economic interests. The development of natural resources has given rise to a marked differentiation in the quality of opportunity opening up to the different sections, while the boundaries of the economic provinces set up in this wise are further emphasized by a general conformity to topographic features disfavoring intercommunication. Thus this country is displaying a steady drift toward economic variation and specialization among its members.

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[1] On the Pacific slope and in the Southwest oil takes the place of coal in this respect.

[2] The organic raw materials are less significant in this respect than mineral resources, since the former are reproducable and not so exclusively focussed at specific points.

But national well-being is dependent upon economic unity no less than upon social unity. The Civil War, in the last analysis, had its origin in discordant economic sectionalism. A military expression of domestic discord is outgrown, but civil strife is not the sole misfortune that may arise from cross interests. Without economic unity a definite economic policy is nationally unattainable. And with no formulated economic policy, one of the two prime functions of government is reduced to the rank of partisanship, and industry is left to the paralyzing influence of uncertainty as regards the future of prospective operations. Thus far the divergent economic interests of the various sections of the country have not permitted the establishment of a constructive economic policy satisfactory to the Nation as a whole.[1]

Elements too numerous to specify enter into this sectionalism of interest, but the most conspicuous contributor to the outcome is the presence or absence of resources productive of mechanical energy. Given a region endowed with an ample supply of coal, for example, and all the other elements of industrial activity gather in the manner of an accretionary growth. Even the crudest raw materials tend to be drawn to the sources of energy in greater measure than is found true of the reverse relation. Other attractions, to be sure, such as labor supply, markets, and transportation facilities register strong claims tending to diffuse and spread the focus of development, but industrial concentration never migrates beyond the convenient reach of power, which therefore sets the outside bounds to industrial range. Thus certain naturally favored sections of the country have come to have a predominant interest in manufacture, while other sections in the rôle of producers and consumers for the manufacturing areas are led to react to motives and economic interests foreign and even antagonistic to those of manufacture. Where such a situation is permitted to develop in accentuated form, an economic policy satisfactory to the two extremes would appear to involve a type of concord foreign to human nature.

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[1] The lack of a constructive economic policy in the United States is more than a negative matter. The deficiency is responsible for such items as a nitrogen problem, a potash problem, a manganese prombem, and others, which war conditions have made apparent—to cite merely a few examples in the realm of mineral resources.

The influence of energy resources in an unfavorable and favorable direction may be illustrated by two examples; one drawn from conditions obtaining in New England, and the other taken from recent industrial developments in the South Atlantic States.

In New England the foundations of industrialism were laid during the régime of water power. With the advent of steam power the abundance of coal available to the Middle Atlantic States set up a strong counter attraction which entailed a steady migration of industry away from the New England section, since this area contains no coal, and is marked by physiographic conditions which provide inadequate gateways for rail transportation and necessitate a roundabout rail-to-water-to-rail service exposed to all manner of exigency.[1] Still, with the advantages of its early start, New England maintained a powerful asset in the form of skilled labor, and the weight of this factor has overbalanced the lack of an adequate power supply in those special forms of industry involving specialized workmanship. These, therefore, still prevail and reflect the peculiar color of the situation. But in the newer industrial sections elsewhere skill of workmanship is in process of development, and is steadily lessening the attraction of an advantage which transiently favors New England. In time this factor will be practically neutralized, and with continued inequality of power supply New England will see its industrial life narrowing under the cumulative weight of a growing handicap. This is an example, then, of how a natural power supply may create a development in one part of the country at the expense of another section, a circumstance not making for unity of interest.

The South Atlantic area resembles New England in respect to power resources; coal must be hauled in from a distance and water power is fairly abundant. But whereas the industrialism of New England is the oldest in the country, that of the South is among the youngest. Here, indeed, the growth of industry has been largely a matter of the past 15 or 20 years, subsequent, therefore, to the introduction of electricity as a motive force. In consequence much of the upgrowth is built upon the use of hydroelectric power, and tends to be distributive—that is to say, *natural*—instead of a forced growth in proximity to localized coal belts. Coming into action late the industrialism of the South, unhampered by tradition and unencumbered by obsolescent power establishments, took over the practice best suited to its needs. Thus while the Northeastern States form an illustration of centralized industry, establishing itself first in New England and migrating later to the Central Atlantic States and thence westward, the South displays a regional deployment of industry, nowhere intensely focussed, but spread, on the contrary, in diluted form over a large area. The contrast is suggestive; for permanence, for national well-being, for the common good, it would appear that a balanced economic life in which each section manufactures, in large measure, its own products is preferable to a highly intensified manufacture setting up its own interests in opposition to the more extensive producing areas. The South presents an example of power supply disposed to create a normal development from within, with minimum detraction from the opportunities peculiar to other sections.[1]

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[1] The weakness of New England in this respect was very conspicuous during the past winter.

These are but two illustrations of fields in which power supply is a strong economic force. Each section of the country, in point of fact, has its own peculiar reflex to this matter. The Pacific coast, for instance, has a specialized and acute power problem to meet; there the rich oil fields of California launched a period of industrialism which this source of power can not much longer sustain. The industrial life of this whole section is threatened by the impending decline of its oil fields. Similarly with the Southwest. The power influence, then, is country-wide—here throttling established industry; there leading to overbalanced growth; elsewhere retarding needed developments; rarely promoting well-rounded economic growth; on the whole, making for divergence of economic interest.

This situation, undesirable as it stands, is bound to grow worse if matters are left to untrammelled evolution. Human labor is mobile; it is becoming standardized, even nationalized; cheap labor locally restricted is disappearing. Thus the factor of labor supply is losing its distributive effect upon industry. In consequence, the presence of mechanical labor (power) will become an even greater centralizing force than heretofore; manufacturing districts will tend to be more strikingly developed than ever. The natural tendency, in short, will be toward the building up of centralized industry enjoying monopolistic advantages of power supply, a condition in itself constituting a restraint in respect to the adequate unfoldment of other industries beyond the reach of the favored source.

Such an interplay of economic forces is complex and proclivities can not be expected to travel far undeflected by new conditions, but whatever the uncertainties of the matter, the power situation merits attention in respect to its present untoward bearing on economic policy. If a constructive economic policy is desirable for this country, and if the conclusion is valid that the power supply represents a force now working against the unification of economic purpose into a national policy, but capable of direction toward such an outcome, the whole matter becomes a fundamental issue which may not be ignored. In short, a coordinated and balanced development of the coal and water-power resources of the country, which will follow from the establishment of an adequate common-carrier system of transmission lines, will serve to equalize industrial opportunity and therefore to unify the economic interests of the country so that a constructive economic policy aggreable to all sections may win country-wide support.[1]

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[1] The Government project at Muscle Shoals may prove to be a disturbing factor in the present distributive unfoldment of southern industry.

But in addition to its bearing upon national policy, a distribution of power advantages will make for an indirect but very significant gain in the matter of transportation; for industry may then strike a more perfect balance between the location of raw-material sources and markets. As the matter now stands, the adjustment is a compromise between three main factors, of which the position of the fuel source is dominant, and the industrial centralization resulting is in considerable measure responsible for the "bottle-neck" restrictions in the transportation layout of this country—a pattern that has become a conspicuous source of transportation weakness during the past year. The nationalization of industrial opportunity through equalized power supply will permit the upgrowth of new industrial activities in positions which will impose a lessened relative burden upon the railways and diffuse the intensification of responsibility that is now bearing with growing force upon the necklike restrictions in the neighborhood of present industrial centers.[2]

ENLARGEMENT OF INDUSTRIAL OPPORTUNITY.

We have seen that power supply constitutes a strong attractive force, leading under natural conditions to marked industrial concentrations in certain parts of the country. The unfavorable bearing of this circumstance upon the attainment of a national economic policy is noteworthy and constitutes an argument for directing the sectionalizing force of power supply into more distributive channels than it seeks of its own accord. The most effective means toward a better balanced industrial growth in this respect is afforded by electricity, which lends itself to generation at fixed points in coal regions and at water-power sites, and to transmission thence to adjacent areas in such manner that, if the growth as a whole be properly shaped, a much larger portion of the country may be served with power on terms of equality than is now the case. Thus can power be turned away, in considerable measure, from its present dangerous facility in accentuating diversity of economic interest and made to contribute to the nationalization of industrial opportunity.

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[1] In a sense we come here upon one of those circles which so often block progress; a constructive economic policy is essential to a proper development of the power supply; such a policy is hindered from coming into existence by the present haphazard status of the power supply with its contribution to economic sectionalism.

[2] The gains in inland waterway transportation and in western irrigation that would come as incidentals in a broad development should not be overlooked.

But just as coal contains valuable commodities as well as stored-up energy, so electricity is not merely a convenient form of power, but is a new and profoundly important chemical agent as well. In this sense electricity represents a fresh industrial factor which is just beginning to come into play and bids fair to make for itself a master range of activity. Electricity, then, is not only capable of distributing industrial opportunity; it is competent at the same time of infinitely enlarging the scope of industrialism. The opportunity in this direction is so significant and has so recently become apparent that the field merits a close view in connection with the whole matter of power supply.

This field of special electrical service, in contradistinction to the application of electric energy as a motive force, is covered by the term "electrochemistry," which is the art of applying electrical energy to the furtherance of chemical operations. The aptness of electricity for this purpose has proved so great that in scarcely more than a decade there has developed a large number of electrochemical industries, in addition to a growing range of superior adaptions in established industries and in the realm of metallurgy, with the setting up of a new branch of the latter known as electrometallurgy. Thus electrochemistry has not only facilitated ordinary industrial activities in many directions; it has opened an unbounded territory never before traversed by industry.

The facility of electricity in this new realm is due to its capacity for generating heat under conditions open to exact control, over high temperatures not attainable by fuel combustion, and in absence of gases, together with the exertion of a chemical force of decomposition independently or in conjunction with the heating effect. Thus electrochemistry operates through its dissociating effect upon solutions and melts, a process technically called "electrolysis"; through discharges in gases; and by means of electric furnaces. Upon these operations depend the manufacture of alkalis, chlorine, atmospheric nitrogen, graphite, artificial abrasives, and calcium carbide; the production of aluminum and many of the steel-hardening metals; and the refining of gold, silver, and copper—to mention merely the most conspicuous attainments of the electrochemical art.

The achievements of electrochemistry to date are to be credited mainly to the region around Niagara Falls and to foreign countries, especially the latter. Elsewhere in the United States there are relatively few electrochemical activities. Such as have been established are in the vicinity of choice water-power sites or, as in the case of recent atmospheric nitrogen fixation plants, subsidized by the Government. But, by and large, electrochemical industries are grossly undeveloped in this country, relative both to their intrinsic importance and to their upgrowth abroad; and while a considerable expansion has resulted under the stimulus of war prices, the course of progress is under the handicap of power costs running far in excess of what is offered in Canada and abroad. Since power is a large item of expense in most electrochemical activities, its high cost in the United States is not only preventing development, except along specialized lines of high-value small-bulk products, but is causing an emigration and settlement of such industries in other countries offering a more genial atmosphere of power costs. Not only this, but the tide of emigration is actually affecting the industries already established at Niagara Falls. On the whole, then, counting off war-time exuberance, our electrochemical industries while growing in an absolute sense are relatively stationary, if not actually retrograding. That is to say, our electrochemical needs are growing faster than our electrochemical industries, which means that an increasing dependence upon foreign developments is under way.

If the high cost of electric power in the United States is blocking adequate electrochemical developments, we should take time to examine the scope of the fields that are being retarded by this circumstance. Such a retardation, of course, is difficult to visualize, for its most important area consists of what has not been accomplished; or, rather, of the margin between current and possible attainments, so far as determined by conditions of power supply. Yet the prospect can be swept, even though we may turn aside before coming up with it.

In the realm of metallurgy, electricity opens to use a number of metals not commercially extractable from their ores on any other terms. The most conspicuous example is aluminum, which was a chemical curiosity until thus made available; but such metals and elements as magnesium, calcium, sodium, potassium, cerium, and silicon are also coming into prominence, although the applications of these newer additions are still in their infancy. It is not unworthy of note, although the bearing of the fact may not become conspicuous for many years, that electrometallurgy offers a means for turning the more common and leaner mineral materials to account when the exhaustion of the rather limited and rich concentrations heretofore exploited shall have been accomplished.[1] For the manufacture of a great number of metallic alloys, such as ferromanganese, ferrochromium, ferrotungsten, and others needed to give to steel the various special properties demanded by its many applications, electric power is essential, while for the production of iron and steel the use of electricity is finding a growing application. Indeed, many "metallurgists in active practice in the United States are convinced that the time is rapidly approaching when all steel made will be passed through the electric furnace to receive its final refining and its finishing touches. We may safely look forward to the establishment of not only hundreds but possibly thousands of electric steel furnaces."[1] In the metallurgy of copper, zinc, and tin electricity is coming into play, while in the refining of metals it is affording the means for recovering many constituents formerly going to waste, in addition to producing products of such purity as to open up new uses not previously enjoyed.[2] The United States is the greatest producer of metals in the world, and proper electrical-power development will give a great impetus to the advancement of the mineral industries.

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[1] In this connection it may be recalled that the valuable elements available solely by electrochemical means constitute nearly half of the earth's crust, while such useful elements as copper, lead, zinc, silver, nickel, tin, and the like, available before the advent of electricity, comprise together less than 1 per cent. This takes no account of the 4½ per cent of iron present, but electro-smelting may come to represent the only means for handling the lean occurrences of this metal.

No problem is more fundamental to any country than the matter of food supply, and electrochemistry has a very direct bearing in this respect through its promise of lending assistance in producing fertilizers. Of the three important fertilizing materials—nitrogen, phosphorus, and potassium—nitrogen may be drawn from the atmosphere by the expenditure of electrical energy; cheap electrical power offers an immediate means for doing away with the cumbersome method of converting phosphate rock into acid phosphate, with its consequent burden upon transportation and upon sulphuric acid manufacture;[3] while the locked-up stores of potash held in unlimited amount in widespread areas of silicate rocks must eventually be drawn upon and presumably with the help of the electric current.[1] It is scarcely too much to say that the fertilizer industry in the course of a decade or so will undergo a radical change, in which importations of Chilean nitrate, German potash, and Spanish pyrite will be a thing of the past. But the course of progress will depend very much upon the conditions surrounding the supply of electrical power in this country; this matter will determine the speed of advancement and reflect in some measure in this respect upon the cost of living.

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[1] J. W. Richards, Electric furnace metallurgy, Proc. Second Pan American Scientific Congress, vol. 7, 1917, p. 265.

[2] The United States Bureau of Mines has recently announced the perfection of an electric smelting furnace that may be revolutionary in the making of brass. The use of this furnace will replace costly crucibles of imported clay and graphite and reduce the losses incidental to the older process by an amount estimated at $3,000,000 a year in normal times and perhaps $10,000,000 a year in war times, besides contributing more healthful working conditions. Such announcements are suggestive of the tremendous latent possibilities in the field of electrometallurgy.

[3] The Bureau of Soils of the Department of Agriculture, in cooperation with the R. B. Davis Co., of Hoboken, N. J., has recently conducted important experiments in this field, with results published in an article, "The use of 'mine-run phosphate' in the manufacture of soluble phosphoric acid," by William H. Waggaman and C. R. Wagner in the Journal of Industrial and Engineering Chemistry, May, 1918, pp. 353–355. It is found that the manufacture of pure phosphoric acid from high-grade phosphate rock at the mines by means of an electric furnace comes to about $65 a ton of available phosphoric acid, which is some $12 higher than the cost of an equivalent availability in the form of acid phosphate as conventionally made by treating high-grade phosphate rock with sulphuric acid. But by manufacturing phosphoric acid from mine-run phosphate rock, thus eliminating part of the mining cost (and incidentally greatly enlarging the yield of a deposit), and treating high-grade phosphate rock with the phosphoric acid so produced, a double superphosphate is obtained containing three times as much phosphoric acid as ordinary acid phosphate and at a cost of around $46 a ton of available phosphoric acid. In the process the item of power amounts to roughly two-thirds of the total

In the field of manufacturing, electrochemistry occupies a unique place. It has already created a number of products of fundamental usefulness, while the latent opportunities for the future are very great. The development of artificial abrasives, especially carborundum, superior to natural abrasives, has greatly facilitated many processes of mechanical manufacture, such as the making of automobiles, ordnance, and other materials; the production of calcium carbide has made the acetylene lamp possible, with inestimable benefit to thousands of mines the world over, which have thus been freed from smoky oil lamps and flickering candles; and the manufacture of artificial graphite is rendering a useful service as a lubricant in conserving energy. These products, which are of much greater significance than may be measured by the pecuniary value of the output, have all been developed at Niagara Falls as result of the abundant electric power earlier available there and are made from

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cost of the finished product. This goes to show that while under present conditions the process verges on being a commercial proposition, an appreciable reduction in the cost of power, even under post-war conditions of cheaper sulphuric acid, would bring the electric-furnace method into competition with the old acid process. The gain in transportation accruing from the shipment of a commodity of three times the present concentration and the enlargement in the phosphate reserve made possible by bringing into play phosphate rock containing more than 3 to 4 per cent of the combined oxides of iron and aluminum (material not usable in the present acid process) commend the whole matter to careful consideration. It should be remembered, too, that of fertilizing materials phosphoric acid appears to be the only one which, from present knowledge, is absolutely limited in amount and therefore demands unusual care in its utilization.

[1] "With respect to the necessary supplies of plant foods other than nitrogen, it has not as yet been seriously considered to utilize electric power, but, speaking to electrical engineers, I can say that the extraction of potash from feldspathic and granitic rocks by electrolysis presents by no means an insoluble or even, in my opinion, a difficult problem. It is perhaps the easiest way that has been as yet proposed to artificially obtain potash, which only awaits cheap enough power to become a reality. I need only remind you that in the silicate rocks of which our mountain ranges are composed, there lie dormant untold billions of tons of potash, to show that when the proper time comes we will not want for raw material. On this special topic I am well informed, for I have made a close study of it in the laboratory and in the field for many years." (A. S. Cushman, Water-power development and the food problem, Proc. Amer. Inst. Electr. Eng., May, 1916, p. 547.) Since this was written, as noted above, the electric-furnace production of phosphoric acid has almost become a commercial possibility—so rapid is progress in such matters. Also, part of the potash even now being produced in the United States is precipitated from waste fumes from cement plants and blast furnaces by means of the discharge of an electric current. Thus the statement above bids fair to be realized, if not literally, at least through the by-product recovery of potash by means of the electric current.

raw materials of the commonest and cheapest kinds, such as sand, lime, coke, and others. Further products, too numerous to specify, are being commercially launched or are in the experimental stage in the works and laboratories of that electrochemical center. An important industry has also developed in the electrolytic manufacture of sodium and chlorine, and their numerous compounds, used in large quantities in a wide variety of other industries, which are made from common salt—a widespread and cheap material. It would appear that one striking characteristic of electrochemistry is its ability to convert into useful products the commonest and cheapest of everyday materials. It holds forth in this sense the prospect of the highest type of constructive economic service.

On the whole, then, electrochemical industries and applications have developed in the United States to some extent in spite of high electric-power rates, but the lines of development have been those in which the advantages to be gained were conspicuous and the operations have been largely confined to Niagara Falls. In the vaster range of possibilities, in which the opportunities were not so outstanding, high rates and lack of available power have been sufficient to head off an incalulable range of prospective enterprises, to the country's serious economic loss. Indeed, if electric power were made available in quantity at rates half the prevailing tariff, the upgrowth of electrochemical industries would overwhelm the previous attainments along this line.[1]

The whole field of electrochemical development in the United States is dependent in the last analysis upon the quantity and price of electric power. And in both respects the power situation as it now stands is inadequate. Unless we are prepared to see the electrochemical industries which we now have emigrate in part to foreign countries, and unless we are also willing to face a stagnant condition in respect to a wide range of important industrial developments, the whole matter of our power supply must come up for attention. This matter does not concern one section or one class; the field is country wide; the outcome concerns both industry and the public interest. And labor in particular will find a concern in this affair, for only by cheapened mechanical power can a generous rate of human compensation be sustained in the face of cheaper labor, both human and mechanical, on the European market.

SUMMARY.

Modern society is dependent upon industrialism, the material framework of civilization.

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[1] There is a great stir in the South at present over the prospects of a great electrochemical industry growing up within the reaches of the Government nitrate plants at Muscle Shoals, Ala. The price of power will, of course, be the critical factor conditioning the outcome.

American industrialism differs from the industrialism of other nations in two respects; it places unusual emphasis upon the employment of power and it couples an advanced industrial development, which means a high standard of living, with a vast expanse of territory.

Each of these conditions imposes a special demand upon transportation, and the two combined have given rise to transportation difficulties that are threatening to throttle the economic life of the country.

If unrelieved the situation will entail a deterioration in the standard of living.[1] The effects of a lowered living scale so caused will not fall evenly the country over, but may be expected to be selective to the disadvantage of unfavored sections, with the setting up of economic discord and sectional dissension in the place of national unity.

The issue can not be adequately met by furthering the development of the railways alone, for already this type of carrier has been pushed to such a point of overdevelopment as to constitute a critical weakness in the economic structure of the country. The source of the disqualification lies not merely in the sheer magnitude of the responsibility which the railways support, but also in their notably inferior elasticity in respect to industrial expansion as compared with the processes of manufacture. The power supply is the chief single contributor to both conditions of default. It not only comprises, mainly in the form of coal, more than one-third of the total freight of the country, but the dependence upon freight-hauled fuel on the part of an expanding industrial activity places an overweight of burden upon transportation by virtue of the fact that coal, raw materials, and finished products represent three additional units of haulage to be reckoned with for every added unit of production.[2] Hence the logical way to correct the transportation unfitness of this country is to attack the matter through improvement in power usage.

Three principles of transportation underlie industrial growth, and industrial activities in general conform to their prescriptions as a matter of course. These factors are represented in (1) the employment of suitable facilities for the task of transportation, (2) the advance elimination of superfluous weight, and (3) the full utilization of the material transported. These conditions are seen to be the merest common sense; illustrations of conformity with them are on every hand; in the matter of power alone they have been utterly disregarded. In the working out of these principles, national experience has shown (1) that a transportation system of country-wide scope serving a community interest must be of a common-carrier order subject to public oversight—such has been the lesson of the railways; (2) that in the realm of production, which has to do with the advance elimination of superfluous weight, competition is desirable and should be as unhampered as possible; and (3) that in the field of manufacture and consumption the attainment of full utilization stands in need of constructive help, that here competition unaided is incapable of employing to full effect the principle of *multiple production.* Applying these conceptions to power we find that the situation is at fault, because (1) there is no common-carrier system for the transmission of energy, although the development of electricity permits the power materials to be freed of weight at the source and enables the energy of water power to be utilized; (2) the presence of the railways, in the absence of special facilities for electric transmission, has prevented competition from becoming effective in the direction of the advance elimination of weight; and (3) the failure of this country to recognize the principle of multiple production and vitalize its latent force has held private initiative impotent to use fully the energy materials provided.

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[1] The situation, as a matter of fact, is already displaying its ability in that direction.

[2] See pp. 10–11 for the necessary qualifications.

The righting of the power situation requires (1) the establishment of a comprehensive system of electric transmission lines to be administered as a common-carrier system like the railways. (2) The provision of such a system will necessitate the coordinated growth of central power stations in coal fields and at water-power sites, and in doing so will open to business enterprise a tremendous field of opportunity hitherto closed off from entry, and thus lead to the balanced development of the two major energy resources. (3) The principle of multiple production, recognized and incorporated in national policy, will supplement the additional service gained through the organized employment of the electrical principle; applied to the production of coal-generated electricity, and, through the medium of municipal public utility plants, to the distributive employment of coal, this principle will effectively correlate the recovery of the commodity and energy values, so as ultimately to effect a full saving of the former and an increased gain of the latter, thus permitting a further relative diminution of the amount of fuel calling for transportation in bulky form. The first two points reduce themselves to a single issue, which is purely a business proposition to be handled by a business organization; the third item is more intangible and it is matter of policy, which, therefore, can not be delegated or otherwise handled in objective fashion.

The provision of a common-carrier system of transmission lines, in brief, is the key to the whole problem. Its establishment will remove the retarding influence of high interest rates and antagonistic misunderstanding that has blocked water-power development, and will afford the point of departure from precedent in favor of coal-field generation of electricity. Owing to the magnitude of the issue and the manifold lines of progress directly at stake, the development will provide a nuclear point for the establishment of a constructive economic policy, needed not merely for the full development of this field but as well for the proper unfoldment of the industrial possibilities of the country in general. As such a policy has not developed in the past because of economic sectionalism growing chiefly out of an unequalized development of the energy resources, the nationalization of industrial opportunity attainable through a balanced development of power supply will clear the path of the main obstruction to unified action.

Thus specific action in respect to establishing a common-carrier system adapted to the power needs of the country will not only go far toward solving the problem of transportation, but it will improve the fuel supply, correct the economic fallacy of drawing upon capital resources while neglectful of income, contribute to the recovery of the values now lost in the consumption of raw coal, lead to an adequate development of electrochemical activities, cut off a needless annual expenditure running well beyond the billion dollar mark, and constitute a potent contribution in the direction of stimulating the upgrowth of a constructive economic policy of national scope attuned to the needs of modern industrial development.

PUBLICATIONS OF THE DIVISION OF MINERAL TECHNOLOGY, U. S. NATIONAL MUSEUM.

Publication 2421. Sources of nitrogen compounds in the United States, by Chester G. Gilbert. Issued June 30, 1916, Smithsonian Institution. 12 pp.

Nitrogenous compounds are essential not only to self-defense, but to the country's capacity for self-support, and to be effective the source must be such that the products may be adaptable to meet either requirement. This paper reviews the merits of the three principal processes for manufacturing nitrogen compounds from the atmosphere, with the following conclusion: The arc method has not thus far demonstrated the capacity to meet the agricultural requirement at all or even the defense requirement efficiently. Definite knowledge concerning the Haber process is lacking, but its record of achievement is against it, and it would seem, moreover, unsuited to American conditions, at least in the present state of its development. The cyanamid process is capable of a development which will meet the requirements for a cheapened nitrogenous fertilizer source whose form of nitrogen content is readily convertible to nitric acid. The process is already a prominent factor in the economic well-being of most countries of older civilization and is capable of similar extension in the United States.

Bulletin 102, part 1. Coal Products: An object lesson in resource administration, by Chester G. Gilbert. Issued November 17, 1917. 16 pp., 11 pls.

The chemical industries of this country are inadequately developed; in fact, up to the outbreak of the present war we had relatively few chemical industries. Yet no field of industrial activity is more essential to the country. The most important of all the chemical industries is that represented in the manufacture of coal products. The purpose of this paper is to bring out the reason for the lack of the chemical industries in general and the coal products industry in particular, with a view to determining where the fault lies and what should be done to correct it.

Bulletin 102, part 2. Fertilizers: An interpretation of the situation in the United States, by Joseph E. Pogue. Issued October 10, 1917. 22 pp., 1 pl.

The fertilizer resources of the United States are viewed in the light of their importance under war-time conditions, when, on the one hand, an increasing supply is needed for the production of an added output of foodstuffs, and, on the other, the foreign sources of supply from which much of our mineral fertilizer is drawn have been cut off or endangered. The rather remarkable circumstance that this country has been dependent upon Chile for nitrogen, upon Germany for potash, and upon Spain for pyrite used in the manufacture of sulphuric acid is pointed out in respect to developing national independence as regards these fundamental materials. The paper is accompanied by a chart which shows in one expanse the whole fertilizer situation with particular regard to the effects of the war upon it. The purpose of the paper is to emphasize to the general public as well as to those more directly interested in fertilizers the importance of dealing with this matter as a broad and fundamental problem affecting the basic matter of food supply.

Bulletin 102, part 3. Sulphur: An example of industrial independence, by Joseph E. Pogue. Issued Nov. 7, 1917. 10 pp., 1 fig., 3 pls.

Two sulphur deposits near the Gulf coast in Louisiana and Texas, worked by an ingenious and efficient mechanical process, not only are supplying practically all of the crude sulphur in this country, but their development has shifted the world's largest sulphur industry from Sicily to the United States. The geological occurrence and method of working the Gulf deposits by means of the Frasch process are described in nontechnical language. The bearing of these deposits on the sulphuric-acid situation is discussed and the need pointed out for a determination of the sulphur resources present in the whole Gulf region, with a view to defining a proper adjustment between the needs of the sulphur industry and the sulphuric acid industry.

Bulletin 102, part 4. Coal: The resource and its full utilization, by Chester G. Gilbert and Joseph E. Pogue. Issued Feb. 21, 1918, 26 pp.

The cost of fuel in the home is roughly four or five times the first cost at the mine. In other words, the cost to the consumer is out of all proportion to the price at the producing end. This discrepency means an extravagant price for fuel in the home and is due to wastefulness of economic procedure all the way down the line between production and consumption. It is the purpose of this paper to analyze the situation and point out economic changes needed to better conditions.

Bulletin 102, part 5, Power: Its significance and needs, by Chester G. Gilbert and Joseph E. Pogue. Issued ———, 1918.

In this country tremendous emphasis is placed on the use of power; the result is a growing burden on transportation which must be solved. The present transportation difficulty is in a measure an expression of this problem. The purpose of this paper is to develop the general nature of the situation and suggests the character of remedial action called for.

Bulletin 102, part 6. Petroleum: A resource interpretation, by Chester G. Gilbert and Joseph E. Pogue. Issued Aug., 1918. 76 pp., 12 figs., 3 pls.

Petroleum is of particular significance because, of all our important resources, it is the most limited and involves the highest percentage of waste. Scarcely one-tenth of the value of the resource is recovered under present circumstances, while the unmined supply available under current practice is only about 70 barrels per person. This paper makes an economic study of the resource and the industry engaged in its development and traces the causes of waste to certain maladjustments in the economic situation, pointing out how these may be remedied by a constructive economic policy applied to the matter. The desirability of developing shale oil to replace petroleum as it becomes incapable of meeting the demand is gone into and the advisability of using benzol and alcohol as substitutes for gasoline is considered. The natural-gas industry is also treated.

Bulletin 102, vol. 1. The energy resources of the United States: A plan for reconstruction, by Chester G. Gilbert and Joseph E. Pogue. (In press.)

This paper brings together the substance of parts 4, 5, and 6 of Bulletin 102, together with an introduction and a conclusion that coordinate the details of the discussion and draw forth the main issues. It is concluded that the whole matter involves the threefold problem of fuel supply, power supply, and transportation, and that the entire field may be cleared by (1) providing a common-carrier system of electric transmission lines which will (*a*) lead to a balanced development of coal-power and water-power, and (*b*) serve as a coordinating influence in stimulating by-product recovery from coal in central power stations, and especially in municipal, public utility fuel plants; and (2) applying a constructive economic policy and appropriate legislation to the conditions surrounding petroleum production so as to bring the method of production into conformance with the geological occurrence of the resource. It is believed that these measures would effect economies offsetting, in large part, the cost of the war.

Note.—The papers listed above as parts of Bulletin 102 are members of a series entitled "The Mineral Industries of the United States."

SMITHSONIAN INSTITUTION
UNITED STATES NATIONAL MUSEUM
Bulletin 102, Part 6

THE MINERAL INDUSTRIES OF THE UNITED STATES

PETROLEUM: A RESOURCE INTERPRETATION

BY

CHESTER G. GILBERT
AND
JOSEPH E. POGUE
Of the Division of Mineral Technology
United States National Museum

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1918

SMITHSONIAN INSTITUTION
UNITED STATES NATIONAL MUSEUM
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CONTENTS.

Page.

INTRODUCTION 1

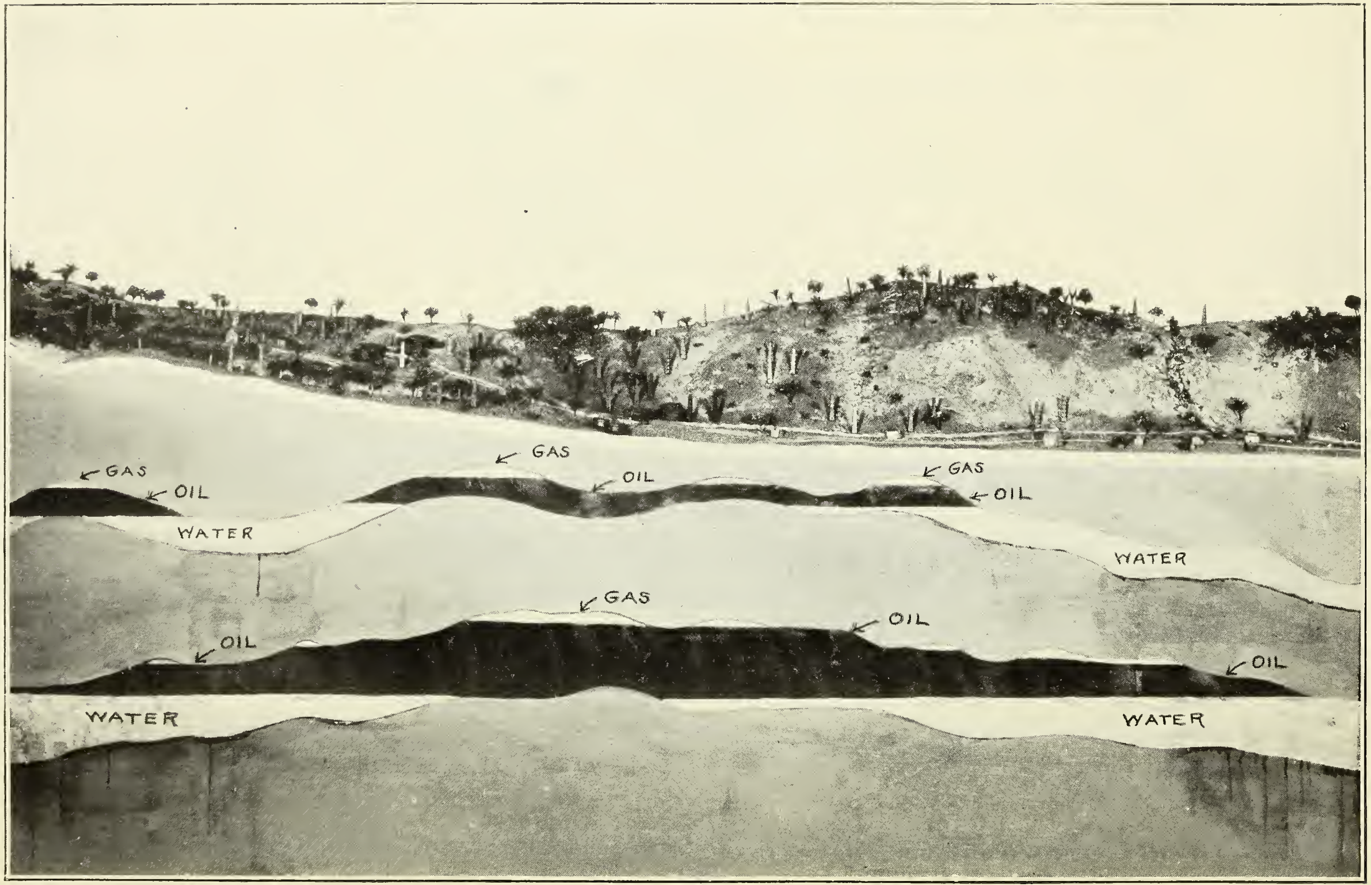
1. THE RESOURCE 2
    - Nature 2
    - Occurrence 3
    - Origin 4
    - Distribution 4
2. THE INDUSTRY 5
    - Production 7
    - Transportation 14
    - Refining 16
    - Distribution 21
    - The natural gas industry 22
3. THE LIMITATION 25
    - The petroleum reserve 25
    - What petroleum exhaustion means 29
    - The war situation 35
4. THE PROBLEM 39
    - Prolonging the life of the petroleum reserve 40
        - Discovery of new oil fields 40
        - Elimination of wastes in production 40
        - Greater extraction of values 44
        - Development of foreign sources of supply 48
    - Development of oil shales 49
    - Development of substitutes 53
5. THE SOLUTION 55
    - The fundamental causes of waste 56
    - The laissez-faire policy 59
    - The advisory policy 60
    - The autocratic policy 61
    - The constructive economic policy 61
        - Discouragement of unrestricted competition in production 63
        - Tapering use of oil as steam-raising fuel 65
        - Encouragement of multiple-product (by-product) development. 67
        - Encouragement of oil-shale development 71
        - Encouragement of benzol and alcohol development 72

SUMMARY 73

FOREWORD.

Mineral resources are coming more and more into prominence as the basis upon which modern advance is built. Their adequate development is a matter of the first importance, and public opinion will be called upon in increasing measure to shape the course of advance in this fundamental field. As the general subject is not one of popular experience, this series of papers is under preparation for the purpose of interpreting in nontechnical language the significant aspects of each resource of mineral origin, in anticipation of a growing demand for concise summations of technical knowledge in a form adapted to current use.

The sources of energy underlie the employment of all raw material, and this paper on petroleum, together with those on coal and power of this series, aim to present a constructive analysis of the fuel situation in the United States.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VIEW OF THE OCCURRENCE AND MINING OF OIL AND GAS.

Photograph of a model in the Division of Mineral Technology ,United States National Museum

PETROLEUM: A RESOURCE INTERPRETATION.[1]

By Chester G. Gilbert and Joseph E. Pogue,
Of the Division of Mineral Technology, United States National Museum.

INTRODUCTION.

Petroleum is of peculiar value to society because it is the sole source of gasoline, the dominant motor fuel; provides kerosene, the most important illuminant outside of cities; and yields lubricating oil, upon which the wheels of industry revolve. In addition, it has come to be an essential fuel in the Southwest and on the Pacific coast, where coal is lacking;[2] is requisite to the operations of an oil-burning navy; and forms the starting point for an oil by-products industry, a branch of chemical manufacture still in its infancy and offering unlimited possibilities of development.

The liquidity of the crude product makes petroleum unique among mineral raw materials, contributing wide commercial availability through the ease with which the substance may be mined and handled; while the magnitude of the resource has given confidence for the extensive mechanical developments essential to its use. Hence the employment of petroleum is deeply rooted among the practices and needs of modern life, and any tendency toward disuse of its essential products,[3] either through undue increase in price or from decline in production, will mark a turning point in material comfort and industrial advantage, the deferring of which becomes an object of universal concern. As the petroleum deposits of the United States have been drawn upon with extraordinary rapidity and the supplies have already suffered serious depletion, the matter of their approaching exhaustion assumes the light of immediate importance. The comfortable assertion that such considerations may be safely left to future generations does not apply to petroleum.[4]

---

[1] An economic study of a limited resource.

[2] Part of the industrial activity of the eastern part of the country is now dependent upon fuel oil.

[3] See p. 65 for qualifications in respect to fuel oil.

[4] " * * * petroleum is a priceless resource, for it can never be replaced. Trees can be grown again upon the soil from which they have been taken. But how can petroleum be produced? It has taken the ages for nature to distill it in her subterranean laboratory. We do not even know her process. We may find a substitute for it, but have not yet. It is practically the one lubricant of the world to-day. Not a railroad wheel turns without its way being smoothed by it. We can make light and heat by hydroelectric power, but the great turbines move on bearings that are smothered in petroleum. From it we get the quick-exploding gas which is to the motor and the airship what air is to the human body. To industry, agriculture, commerce, and the pleasures of life petroleum is now essential." (Franklin K. Lane in Reports of the Department of the Interior for 1915, Washington, vol. 1, p. 16.)

1. THE RESOURCE.

NATURE.

Petroleum, or crude petroleum as the raw or unrefined product is often termed, is an oily liquid varying considerably in appearance according to the locality from which it comes. It is an extremely complex mixture of organic compounds, chiefly hydrocarbons,[1] but substances containing sulphur, oxygen, and nitrogen are also present in small amounts. It contains, therefore, five chemical elements of the first importance in life processes, a circumstance that suggests at once an organic origin and determines the important rôle that this substance is due to play in filling the needs of man.[2]

If crude petroleum is exposed to the air, it gradually thickens until a solid residue is left. The first product given off is natural gas; then liquid components evaporate in the order of their lightness; and the final residue is composed largely of either paraffin wax or asphalt. Petroleum is thus seen to be a mixture of different liquids dissolved in one another and holding in solution also natural gas and solid substances. This conception correlates natural gas as a by-product of petroleum[3] and affords a simple epitome of the changes more rapidly induced when petroleum is subjected to refining.[4] The asphalt lake of Trinidad and the ozokerite deposits of Galicia and Utah represent natural residues from the prolonged evaporation or natural distillation of petroleum.

While petroleums vary considerably in character, they fall chiefly into two classes according to whether the residue yielded is predominantly paraffin wax or asphalt.[5] This broad distinction is of great economic significance, because the paraffin petroleums, occurring chiefly in the eastern part of the country, came first into use and therefore determined the current refining practice and the existing demand for petroleum products; while the asphaltic petroleums, exploited later in the Gulf region and California, found their immediate commercial outlet in the form of fuel. The higher gasoline content of paraffin oils, coupled with the distance of coal from the Californian region,[6] gave free scope to the economic differentiation of the two types.

---

[1] Compounds composed of hydrogen and carbon. These substances are present by the hundreds.

[2] It would be shortsighted to assume that petroleum even now has displayed its full measure of versatility.

[3] Part of the natural gas production of the country, indeed, comes from petroleum wells.

[4] The processes of refining, of course, involve some chemical changes also.

[5] The first are said to have a *paraffin base;* the second, an *asphaltic base,* or called merely asphaltic petroleums. There are also intermediate oils with almost equal proportions of paraffin and asphalt.

[6] The presence of coal fields in California, however, would have scarcely deterred the development of the oil fields of that State, although their presence would afford a pleasing contemplation now.

OCCURRENCE.

Because of its liquidity, petroleum differs markedly in geological occurrence from all other minerals. It appears on the surface in some localities in the form of oil seeps, but commercial quantities of petroleum are found only at depth inclosed within the rocks of the earth's crust. Its occurrence is very similar to that of artesian water, with which, indeed, it is frequently associated. It saturates certain areas of porous rocks, such as beds of sand or sandstone, tending to accumulate where such strata occur beneath denser, impervious layers. Occurring in this way under the pressure that obtains at depth, carrying immense quantities of natural gas in solution, and almost invariably associated with water, petroleum is capable of movement and in general migrates upward until it encounters a layer of impervious rock so disposed in structure as to impede further progress and impound the oil into a "reservoir" or "pool"[1] (see pl. 1 and fig. 12).

The geology of petroleum, therefore, is the geology of rock structures, and the skilful mapping of the surface disposition of rock formations gives the means for determining the structure at depth and hence the position of structural features favorable to the accumulation of oil. When this information is supplemented by careful records of the rock layers encountered as wells are drilled, a three-dimensional knowledge of the earth's crust is obtained, remarkable for its detail and accuracy. Thus by the aid of geological methods the development of petroleum fields may be changed from a gambling venture, to an exact science, and, if the scale of operations be sufficiently large, it may be figured rather closely how much oil can be obtained from a given expenditure of money.[2] Instead of representing the most uncertain venture in the world, therefore, oil production can now be made as definitely an engineering project as the mining of a clay bank.

The migratory character of petroleum, coupled with the general tendency of stratified rocks to occur in broadly undulating folds and shallow domes, gives peculiar significance to the underground disposition of the oil deposit. Thus the process of winning the oil consists in puncturing the structural feature that holds it in restraint so as to give free scope to a movement upward to the surface. Accordingly the position of the oil grows highly unstable as soon as the deposit comes under exploitation and this variability affects the entire geological unit or pool. In consequence the joint ownership or joint exploitation of a single pool results in the inability to apportion the product on any arbitrary basis of vertical boundary planes,[1] and the oil, therefore, is practically no man's property until it is got above ground. This circumstance is almost invariable and the customary method of exploiting the single oil pool by a series of small, independent holdings has cost an inordinate toll of waste and loss.[2] The economics of oil production is out of adjustment with the geological occurrence of oil and the latter, being a physical fact, can not be altered.

---

[1] These words are misleading in that they suggest great open spaces filled with oil rather than areas of oil-saturated rock. Water is sometimes lacking, and then the oil migrates in a different manner.

[2] Another interesting application of geology to oil exploration has been developed by the Standard Oil Co. of California and by the United States Geological Survey. It has been found that the chemical composition of the water encountered by the drill will give some indication of the proximity to oil and hence serve as a guide to a successful development. (See G. S. Rogers, Chemical relations of the oil-field waters in San Joaquin Valley, Cal., Bull. 653, U. S. Geological Survey, 1917.)

ORIGIN.

Few questions in geologic theory have met with more discussion than the origin of petroleum. It is reasonably certain, however, that petroleum in the main is of organic origin and represents the natural distillation products of plants and animals buried in the muds and oozes of ancient swamps and seas. Vast rock formations, indeed, are known which are nothing more than the accumulated débris of innumerable organisms, compressed, hardened, and changed into rock. Fossiliferous limestones, phosphate rock, and coal seams are familiar examples which underlie thousands of square miles of the earth's surface. It would be strange, in fact, if in the process of formation oils were not produced, when organic products to-day, subjected to heat and pressure, yield oily substances not unlike petroleum. Sediments carrying organic remains are sufficiently abundant and widespread to account for all the petroleum that the oil fields of the world give promise of producing.

DISTRIBUTION.

While petroleum is of very common occurrence in traces, areas underlain by commercial quantities are somewhat restricted and fields of great importance are few. Thus in spite of an intensive search for new oil regions and vigorous campaigns of development carried on in all parts of the world, the entire supply comes largely from three countries, as shown in the accompanying chart (fig. 1).

In the United States, the output is derived from a number of widely scattered regions known as "fields," whose distribution is shown on the map (fig. 2), and whose importance is indicated by the charts (figs. 7 and 8.) In a broad way, these fields fall into two groups—those of the eastern half of the United States, bound into a single unit by an extensive system of pipe lines, and those of California, connected with the rest of the country by railroad transportation only.[1] The intermediate fields of Wyoming[2] do not come within this rough geographic classification, but with further development they will presumably be joined by pipe lines[3] with the group of the eastern half of the country. It will be observed that the Kansas-Oklahoma field of the eastern group and the California field are about equal in production and dominate the petroleum output of this country, together contributing over two-thirds of the total supply. (See fig. 7.)

---

[1] It is a rather curious commentary on the obsoleteness of American mining law that vertical boundaries are applied to oil deposits where they have no meaning, but are not applied in the case of outcropping ore deposits, where they are both appropriate and desirable.

[2] See fig. 12.

The development of petroleum production in the United States from 1881 to 1917 is indicated graphically by the chart (fig. 3). From the situation there depicted, two features of particular significance stand out—the slow increase in domestic production up to 1900, less marked than the increase in the corresponding foreign production, and the rapid domestic growth between 1900 and 1917, contrasted with a nearly constant production for foreign countries during that period. This emphasizes the fact that since the beginning of the twentieth century, the rapidly increasing use of petroleum throughout the world has been met largely through the intensive exploitation of American deposits. Thus the United States has assumed a dominant position in respect to this commodity, producing now two-thirds of the world's supply.

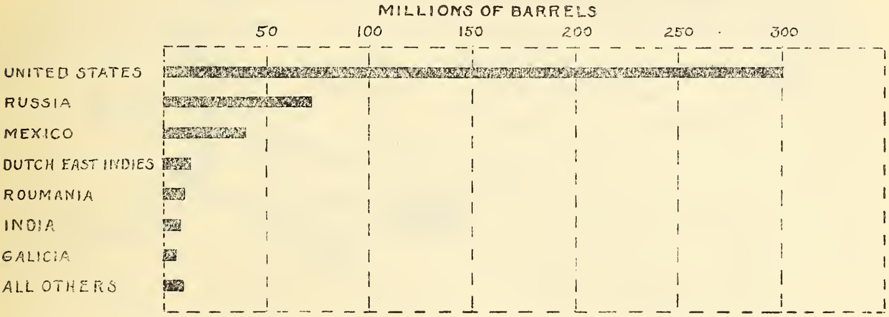

FIG. 1.—WORLD'S PRODUCTION OF PETROLEUM IN 1916. DATA FROM U. S. GEOLOGICAL SURVEY.

2. THE INDUSTRY.

The activities concerned with the production, transportation, refining, and distribution of petroleum constitute the petroleum industry. In quantity, value, and importance of production, this industrial field stands among the foremost in the country. It is notable, especially, for the scope of its operations, which embrace diverse activities usually the functions of separate industries—a characteris-

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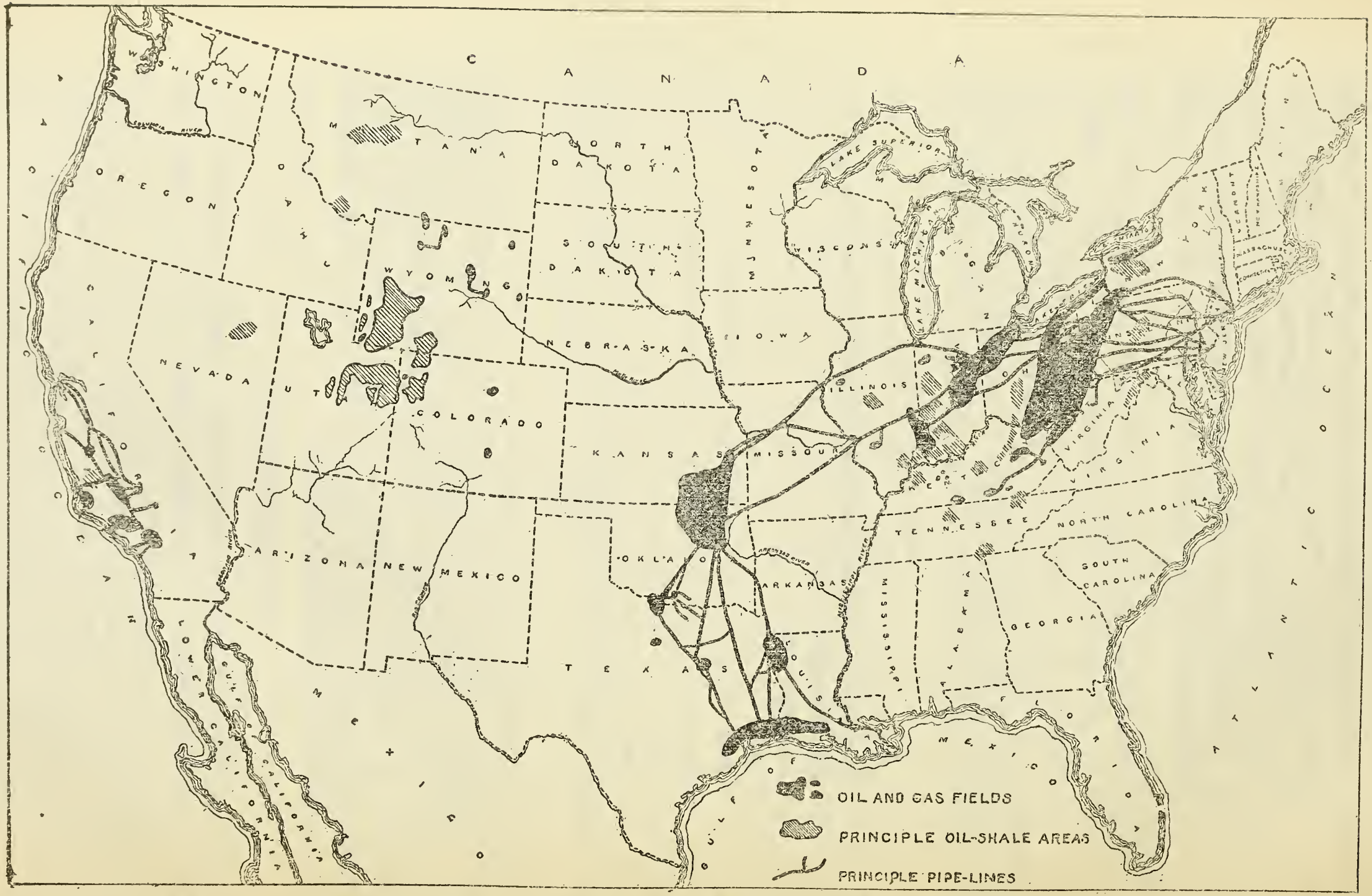
[1] Also by water transportation through the Panama Canal.

[2] Including Colorado.

[3] Probably by way of the shale-oil region of Colorado. (See map, fig. 2.)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SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
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NORTH CAROLINA
VIRGINIA
WEST VIRGINIA
PENNSYLVANIA
NEW YORK
VERMONT
NEW HAMPSHIRE
MASSACHUSETTS
CONNECTICUT
NEW JERSEY
MAINE
ATLANTIC OCEAN
PACIFIC OCEAN
GULF OF MEXICO
MEXICO
LOWER CALIFORNIA
GULF OF CALIFORNIA
OIL AND GAS FIELDS
PRINCIPLE OIL-SHALE AREAS
PRINCIPLE PIPE-LINES

FIG. 2.—SKETCH MAP SHOWING THE DISTRIBUTION OF THE OIL AND GAS RESOURCES, TOGETHER WITH PRINCIPAL PIPE LINES OF THE UNITED STATES. GENERALIZED FROM DETAILED MAP BY JOHN D. NORTHROP, OIL AND GAS FIELDS IN 1916, CORRECTED TO MARCH, 1917, U. S. GEOLOGICAL SURVEY. OIL-SHALE DATA FROM U. S. GEOLOGICAL SURVEY AND OTHER SOURCES.

tic arising from the peculiar nature of petroleum. In most other industries, to cite the most striking distinction, transportation over alien lines separates the producing activity from the manufacturing activity, creating a break between continuity of operations; in the case of petroleum, however, the liquidity of the crude product adapts it to specialized transportation through pipe lines, themselves a part of the resource development. In consequence, the petroleum industry in its ideal form represents a type of industrial activity more highly coordinated than other industries of the present day, affording, therefore, an important object lesson for constructive consideration.

The petroleum industry, in point of fact, however, is not coordinated throughout, but at present breaks into two portions, by no means in complete adjustment—the production of petroleum and the handling of petroleum with its threefold aspect of transportation, refining, and distribution. The conditions of producing crude petroleum are wholly different from those involved in its treatment after it is above ground. This is reflected in the circumstance that over 15,000 individual companies are engaged in the mining of petroleum, while the organizations concerned with the handling of the product are numbered by a few hundred. A large part of the crude production,[1] therefore, appears above ground through the efforts of a great many small operators, while the bulk of the transportation, refining, and distribution is taken care of by a very few large organizations.

PRODUCTION.

Petroleum is won in commercial quantities through wells drilled to varying depths into the crust of the earth. The drilling is commonly done by means of a heavy string of tools suspended at the end of a cable and given a churning motion by a walking beam rocked by a steam engine. This method is known as the standard or percussion system of drilling. The steel tools, falling under their own weight, pulverize the solid rock encountered and literally punch their way to the depth desired. To prevent the caving in of the hole, but especially to avoid the inflow of water from water-bearing formations, the well is lined or "cased" wholly or in part with iron piping, which is inserted in screw-joint sections at intervals during the drilling and forced down to positions needful of such protection. The well does not taper, but if deep changes to successively smaller bores at several points, resembling in section a great telescope.[2]

---

[1] Estimated roughly at four-fifths.

[2] The drilling of an oil well is graphically described by George Fitch in the following paragraph:

"An oil well is a hole in the ground about a quarter of a mile deep, into which a man may put a small fortune or out of which he may take a big one. And he never knows

Another method of drilling known as the rotary system is also in common use, being particularly adapted to regions where the sides of the well tend to cave badly, as in California and some other localities. This system requires more elaborate machinery than the standard, as the drilling and insertion of the casing is simultaneous. The iron casing, indeed, is tipped with a steel bit and rotated so as to bore its way downward like a great auger.

The oil well is marked by a tall wooden framework called a derrick, which permits the string of tools and the casing to be inserted or withdrawn when necessary. It is the presence of derricks that gives the characteristic appearance to an oil field landscape. Oil wells vary from a few hundred feet or less in depth, requiring a few weeks only to drill, to those thousands of feet deep and demanding months of continuous labor before production starts.[1] The cost of drilling normally runs from $1 up to $15 and more a foot,[2] while the rate of progress, except for shallow wells, ranges from about 60 down to 10 feet a day, slowing, of course, with depth. It is apparent, then, that oil-well drilling is a slow and costly process and makes a heavy draft upon the iron and steel industry, consuming indeed about one-twelfth of its output in ordinary times.

A well favorably located eventually penetrates an oil-bearing bed, and the petroleum may spurt forth in a lavish stream under the influence of the natural gas held in solution under pressure.[3] Such wells are called gushers and some pour forth prodigious quantities of oil.[4] Other wells flow with less violence, and many, lacking in

---

until the hole is finished * * *. It takes a couple of thousand dollars, several months, and a couple of noncommittal men in mud-plastered overalls to dig an oil well. They begin by going up about 60 feet. When they have finished their derrick, they hang a drill on it weighing half a ton. Then the men hitch the drill to an engine and punch a 42-centimeter hole in the earth's crust. Sometimes, after they have been punching away for several weeks, the hole blows the derrick into the sky, utterly ruining it. Then the owner shrieks with glee and employs 500 men to catch the spouting oil in barrels. But sometimes the derrick is as good as new when the hole is finished. Then the owner curses and takes the derrick away to some other place which smells oily."

[1] The deepest wells are slightly over 7,000 feet, but such depths are exceptional. The deepest well in the world is near Clarksburg, W. Va., having recently reached a depth of 7,363 feet, according to the U. S. Geological Survey.

[2] This is the cost in normal times. At present, the cost is more than twice the usual figure. Thus to drill a well 3,000 feet deep might now cost from $50,000 to $80,000.

[3] The action is analogous to the rush of soda water from a bottle when the cork is removed.

[4] "On the Fourth of July, 1908, the greatest oil well of the world was struck at San Geronimo, on the Gulf of Mexico, 67 miles north of Tampico. When struck, the oil gushed so rapidly that before the fire in the boiler of the engine running the drilling machinery could be extinguished the flowing oil reached it and burst into a mass of flame which for two months burned 60,000 to 75,000 barrels of oil per day with a flame from 800 to 1,400 feet in height, and 40 to 75 feet in width, making light enough to be seen by ships 100 miles at sea, and to permit a newspaper to be read 17 miles away. After the loss of $3,000,000 the fire was put out, but the oil flowed so rapidly that it could not be carried away or put in tanks, and the English owners saved their oil only by confining it in a reservoir one-fourth of a mile long made by heaping up earth embankments to keep the oil from flowing away like water. Even this well was later surpassed by the Potrero del Lano No. 4 well near Tuxpam, Mexico, which yielded 160,000 barrels a day for some time."—J. Russell Smith, Industrial and Commercial Geography, 1913, p. 409.

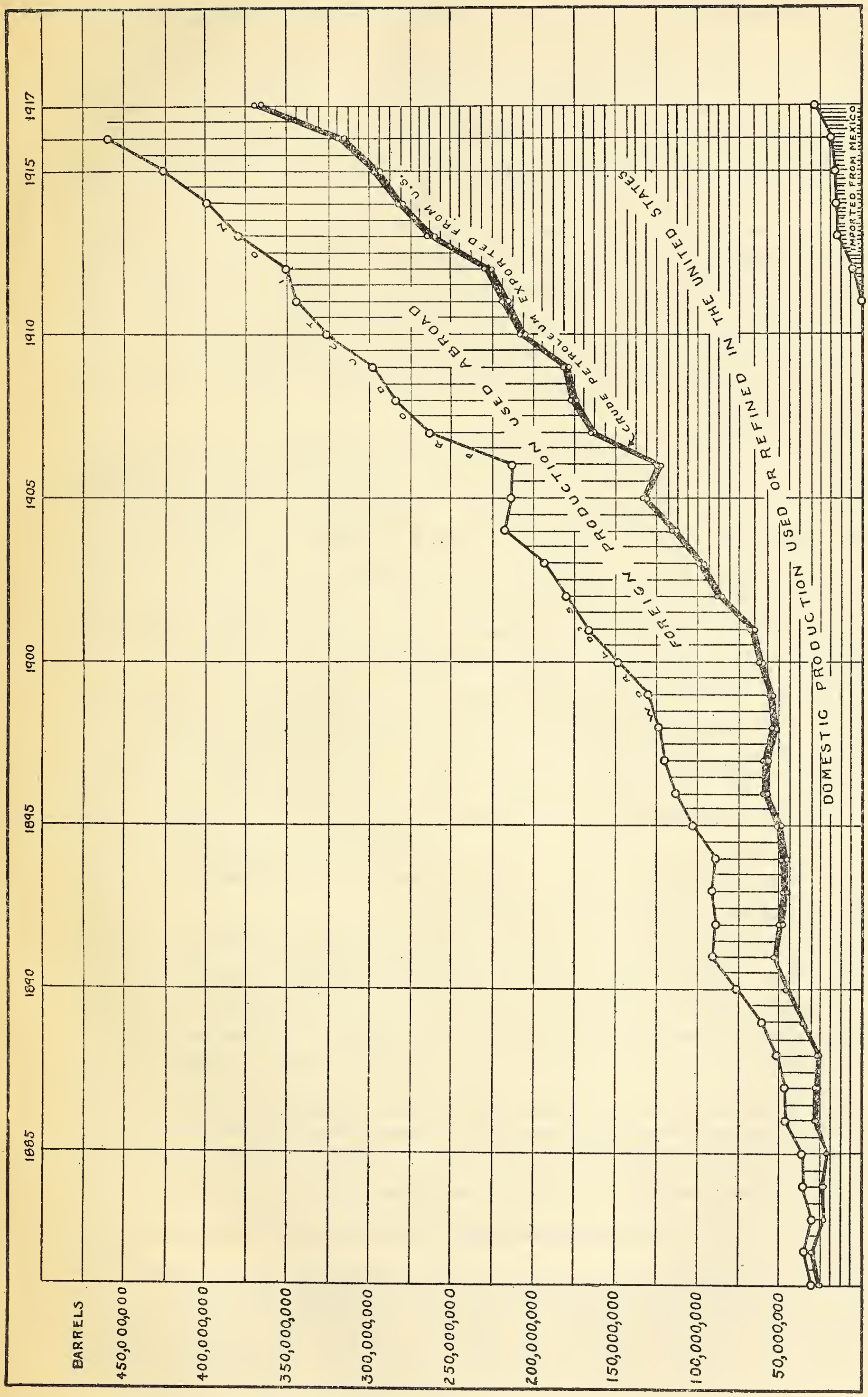

Fig. 3.—Chart showing petroleum used in the United States and the rest of the world from 1880 to 1917. Data from U. S. Geological Survey.

notable quantities of natural gas, yield only under the inducement of pumping. All wells, however, soon reach a maximum production, after which they pass into a period of decline, and eventually become extinct.[1] So inexorable is this procedure that a curve may be plotted in advance depicting the future behavior of a given group of wells.

When an oil well becomes extinct, its nonproductiveness does not signify that all the oil is exhausted. On the contrary, current practice in general leaves over half of the oil underground still clinging to the pores and capillary spaces in the rock. To obtain a greater yield from productive ground constitutes a problem of the first magnitude, and promising results have been obtained by forcing compressed air into some of the exhausted wells of a group, with the result that the laggard oil is swept to the neighborhood of other wells from which it may be pumped.[2]

When a gusher is struck, adequate facilities are often lacking for catching and storing the product, so that veritable lakes of oil gather between quickly thrown-up earthen embankments. Quantities, in such instances, are dissipated through seepage and evaporation, while disastrous fires of spectacular nature are not uncommon. With more careful development, however, field storage tanks shaped like huge cheese boxes are in readiness to receive the oil and prevent the glaring waste inherent in more hasty operations.[3]

Turning attention from the single well to the oil field, we observe that in petroleum mining sustained production depends upon an unbroken campaign of drilling operations. Thus the producers must not only draw oil from existing wells, but at the same time must persist in the drilling of an *increasing*[4] number of new wells and in the location of promising territory in advance of drilling. Any factor that retards any one of these three related activities quickly reacts to cause a falling off in production.[5]

Output, development, and exploration, therefore, must go hand in hand. In a general way, this threefold activity of production is carried on either as a large-scale engineering procedure or as a composite of small, individual operations. Large oil companies engaged in production naturally adopt what might be called the engineering procedure, while small companies and individual operators tend more to follow what is picturesquely termed "wildcat"[1] operations. Thus the production of oil is in part dependent upon stable conditions, but in larger part is still a type of activity which approaches in considerable measure a gambling venture. This is why oil mining is generally looked upon and commonly described as hazardous from a financial standpoint. The hazard is inherent only in small-scale operations.

---

[1] Wells during decadence are spurred into temporary renewals of activity by the explosion of charges of nitroglycerine at their bottoms. The life of an oil well varies from a few months to twenty years or more. The average life of Pennsylvania wells is estimated to be seven years.

[2] See J. O. Lewis, Methods for increasing the recovery from oil sands: Bulletin 148, U. S. Bureau of Mines, 1917.

[3] Only the most carefully constructed tanks prevent the escape of the volatile constituents of petroleum.

[4] As an oil field ages, new wells yield less than the initial yields of the earlier wells, hence a growing number of active wells is necessary to maintain production.

[5] For example there has recently been a strike in one of the Gulf fields, of such a nature as to affect not the current production, but the drilling campaign upon which the production of coming months is dependent. Thus a wave is started which will not be felt until the future; and like all waves, once started, nothing can stop the reaction.

The engineering type of production makes use of skilled geological knowledge in its campaign of oil production. The modern oil company employs a large geologic staff, which determines by detailed field surveys the most promising spots for drilling.[2] The growth of oil geology has been rapid and while, of course, geologic science can not strike oil with every drill, it does multiply by many times the chances of each drilling operation. It has been stated that "the operator who plays geology has a fifty times better chance of striking oil than he who does not."[3]

But in spite of numerous highly organized production activities, the fact remains that the petroleum production of the United States is in considerable measure dependent upon a hit-or-miss plan of exploitation. Were it not for the wildcatter, who stakes his all (sometimes borrowed) on the chance that a random hole drilled in the general vicinity of productive territory will yield the hoped-for return, the output of petroleum in a country which produces two-thirds of the world's supply would fall to an utterly inadequate figure. The gambling instinct is still the prime motive power that lifts most of the oil produced in this country. Familiar is the expression, once an oil man, always an oil man.[4]

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[1] In strict oil-field parlance, to *wildcan* is to drill a well where oil has not been proven to exist, as opposed to drilling a well in the midst of producing wells. Thus both large companies and small may alike engage in *wildcatting*, although, as a matter of course, most of the *wildcatting* is done by small operating units.

A good picture of wildcat operations is given by W. S. Tower in The Story of Oil, 1909, p. 66: "To call a well a wildcat venture means merely that the drilling is done on untested territory, or on land not definitely known to be oil producing. The wildcat operation is, therefore, an out-and-out gambling process by a man who is willing to stake a few thousand dollars against heavy odds that he will find oil at some depths in a drill hole a few inches in diameter. If luck favors him, his winnings may be enormous; if he loses, his only hope is to pull up, leave the hole where his money is sunk. and move to some other place."

[2] The implication, of course, is not intended that small companies do not employ geologic service, but, in general, the smaller the company the less likely it is to be capable of making the necessary expenditure. The Federal Government, through the U. S. Geological Survey, has rendered a signal service to the small operator through its published reports and maps covering oil regions, but the small operator has not in all instances taken advantage of even published geological information.

[3] Dorsey Hager, Bulletin American Institute of Mining Engineers, October, 1917, pp. 1793–5.

[4] An unfortunate and far-reaching consequence of the present method of production is the extension of the gambling aspect into widespread public consciousness, leading to a susceptibility to the purchase of stock in illegitimate oil-mining ventures. The losses involved in the readiness of the public to embrace the schemes of fraudulent oil promoters are untold and have reacted unfavorably upon public opinion in respect to the legitimate industry.

It is not intended, of course, to throw oil production into an unfavorable light by thus focussing attention upon its gambling aspect; to exert onerous effort (such as oil field development demands) under the incentive of rich possibilities of reward is a straightforward and legitimate business activity. It is frequently questioned whether oil development could be sustained without prospect of large pecuniary gain.[1] The point is merely made that under present circumstances petroleum production is dependent upon this psychological aspect, acutely developed, which is both subtle and intangible, yet profoundly important in conditioning the output; this factor must be reckoned with in contemplating the course of the resource development.[2]

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[1] It is interesting to note an English view of this aspect of production: "The large producers and refineries, appreciating the value of the speculative oil seeker, foster rather than discourage his activities. He absolves them from considerable preliminary expense in drilling and proving a new territory. Their work is reduced to purchasing and transporting the raw material when it has been tapped. It is a development which is peculiar to the United States. In other oil-producing countries such a tendency is not supported." (Frederick A. Talbot, The Oil Conquest of the World, London, 1914, p. 58.)

[2] The distinctive "color" of oil production can perhaps be effectively conveyed by means of a number of quotations:

"The great army of men who produce our oil for us are in many cases of the rough-and-ready sort, but they are not penny-splitters and they are not hold-up men. Few of them have diplomas to exhibit, and their English may not be of the best; but they know how to do things with their hands, feet, and heads—and I do not believe that there is a more loyal or a more likable bunch of men in the world." H. L. Doherty.

"* * * the producing branch of the industry * * * is a picturesque blending of temperament, personality, and psychology with all the mingled burlesque and common sense that one would expect from unorganized energy and enthusiasm. Production is largely the outgrowth of the sporadic efforts of many 'wildcatters' of many moods and varying capabilities." H. L. Wood in Sinclair's Magazine, October, 1917, p. 31.

"It is the speculative character of the work that appeals to the American. He is a born gambler, delights in juggling with fortune; with him speculation is second nature. In the quest for oil he has unlimited capacity to gratify his desires to become rich quickly." This last is by an English writer, Frederick A. Talbot, The Oil Conquest of the World, London, 1914.

"Let us consider for a moment the vital question of drilling experimental wells—'wildcatting'—standing at the base of the discovery of new oil fields, without which the industry would dry up. For every field discovered there are hundreds—perhaps thousands—of experimental, worthless holes drilled—'wildcat' wells. The 'wildcatter' is moved to take his long hazard, his big chance, his desperate gamble, through the highly speculative considerations surrounding his work—the hope of a great reward; realizing, however, all the time that the chances are ten to one against his success * * * clearly, the practical course is to leave to the thousands of men who are willing when left free of interference and free to act upon their own volition, the opportunity and the privilege of making the venture—taking the chance. Most of them will lose. The few who gain will deserve their reward. The sum total of their efforts will be for the world at large. * * * As a rule, large companies or corporations have not been the discoverers of new pools or fields, except in very rare instances. They are generally found by individuals or small groups of tenderfeet at the game * * *." Instances taken at random from an article, "The future of the oil industry," purporting to represent the views of the "leading men of the industry," as ascertained by a questionnaire, published in the Semiannual Oil Industry Review, The Evening Post, New York, Mar. 2, 1918.

"* * * The optomistic wildcatter, that virile pioneer of the oil field who cheerfully takes the gambler's chance in the hope of reaping a reward commensurate with the risk." M. L. Requa, War Service of the Petroleum Industry, Oildom, April, 1918, p. 214.

Production and consumption, of course, can not coincide in amount; hence, of necessity, there are reserves of petroleum above ground which serve as an expansion and contraction joint, so to speak, between supply and demand. When there is an overproduction in respect to current needs, the reserves or, as commonly termed, the stocks increase; conversely, with industrial expansion or lessened output, drafts are made upon the stocks, which then decrease. The condition of the stocks, therefore, is a sort of pulse to the crude-oil market, since prices, under the influence of the same factor of supply and demand, fluctuate in like manner. The stocks, under conditions of unorganized production, have come to be unusually great during the past few years, representing roughly in 1916 a six-months' supply.[1] At the present time, under war conditions, the stocks are being rapidly depleted to meet a consumptive demand which is greater than the productive capacity of the country.

The price of crude petroleum at the well varies considerably according to quality, distance from market, and other factors. The paraffin oils of light gravity, such as those produced in Pennsylvania, are the most valuable because they yield the largest percentage of products in demand, while the asphaltic oils of heavy gravity, such as those of California and part of the Gulf region, command a price roughly a fourth of that which the best quality oil enjoys. Thus the Pennsylvania crude commenced 1915 with a price of about $1.50 a barrel and ended 1917 at about $3.75, while during the same period California crude[2] climbed from about 35 cents to practically $1. These two types of oil represent the extremes of quality, with the factor of distance from markets nearly the same in the two instances. Between these limits range the prices of all the other oils of the country, the quotation at any given time and location being a complex of quality and of balance between supply and demand, with all the qualifications that the latter expression involves. The wide range in prices for a single raw material, with the utmost concession to differences in location and composition, suggests an undue discrepancy to be credited against the conditions under which oil is produced.

The dependence of sustained production upon an unbroken campaign of drilling exploration, and the extent to which such a campaign is carried on by "wildcat" operations on the part of small companies and individuals, lead to many perplexing legal and economic difficulties. Land, of course, is rarely owned by the operator, so that he must ordinarily either purchase or lease the oil (and gas) right. The laws connected with oil lands have not been modernized, but are confusing and in part conflicting, so that the operator is put to undue trouble and expense in meeting the legal requirements of his holdings. Moreover, the method of leasing under small-unit operations leads to a wasteful competition between neighboring wells in their race to secure a maximum production within the period of the lease—haste, with waste, being an economic necessity in such instances. In regard to lands owned by the Government, the legal regulations are so ill-adapted to progress that R. H. Johnson and L. G. Huntley in their "Principles of Oil and Gas Production,"[1] remark: "Most of the public lands which seem promising for oil and gas have been withdrawn,[2] since there is universal agreement by both Government and producers that the present law, by which oil and gas lands are taken as placer claims, is utterly unadapted to the industry.[3] The development of the lands which are not withdrawn would best be postponed until a new oil and gas prospecting permit and leasing law is passed, and the oil placer claim law revoked, except where work is already started."[4]

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[1] The stocks have been estimated as follows: On hand Jan. 1, 1916, 186,000,000 barrels; on hand Jan. 1, 1917, 174,000,000 barrels; on hand Jan. 1, 1918, 153,000,000 barrels.

[2] That below 18° Baumé in gravity.

TRANSPORTATION.

One of the remarkable and impressive features of the petroleum industry is the fact that the crude product is transported through a system of pipe-lines that connect the points of production with refineries, markets, and seaports. This method of handling is natural and inevitable with a liquid product consumed in bulk, as evidenced by a somewhat analogous method of transportation adopted for the municipal water supply. While petroleum shares with coal the main responsibility for energizing the mechanical activities of the country, it is interesting to note that crude oil, unlike raw coal, imposes normally no appreciable burden upon the railroads.

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[1] New York, 1916, pp. 112–113.

[2] That is, closed to private development pending a determination of policy. The Secretary of the Interior, in a letter to the chairman of the Committee on the Public Lands, House of Representatives, under date of Apr. 24, 1917, writes: "Six million four hundred and ninety-one thousand one hundred and forty-five acres of public lands believed to contain oil are withdrawn from development. A part of this area is proven territory, in direct touch with pipe lines and refineries, and the product could be made immediately available by the enactment of this measure. I therefore earnestly recommend that H. R. 3232 be enacted at the earliest practicable moment as a war measure." (Committee Print of Departmental Reports on H. R. 3232 and S. 2812, Washington, 1918, p. 4.) The matter is still (July 1, 1918) under abeyance.

[3] See letter of the Secretary of the Interior to chairman of the Committee on Public Lands, under date of Jan. 3, 1916 (published in Committee Print of Departmental Reports on H. R. 3232 and S. 2812, Washington, 1918, p. 8), which states: "Oil and gas lands or deposits are now subject to location and entry under the placer mining laws. These laws have generally been unsatisfactory, both from the standpoint of the prospectors and operators and of the Government. There is nothing in the present law to protect the prospector during the preliminary period, when, through the expenditure of large capital, he is engaged in drilling, and the limitations as to acreage contained in the existing laws are also a temptation to evade, through the use of dummy locations."

[4] It is unfortunately true that mining in the United States has been badly impeded by a set of laws handed down from the past and wholly unadapted to modern conditions of mining. Sporadic attempts, usually unsuccessful, have been made to improve certain details of these laws, but in general American mining law remains a discredit to the Nation. In the present war emergency the country is paying a heavy penalty for its neglect of this matter.

The pipe-lines of the United States, comprising those of the subsidiary companies of the Standard Oil and a number of independent companies, aggregate thousands of miles in length and form a network spread over much of the country.[1] They consist of trunk lines, the longest of which connects Oklahoma with the Atlantic seaboard by way of Illinois, and gathering lines leading into the main channels. The whole system is comparable to the arteries and veins of the human body.

The pipes vary in diameter from 2 to 12 inches, but 6 to 10 inches represent the common sizes. The piping is made of iron plate and is ordinarily placed below the surface of the ground. At intervals of from 15 to 30 miles, according to the viscosity of the oil, are pumping stations, where powerful pumps seize the spent oil and force it forward with renewed vigor. In the case of heavy, viscous oils, such as those of California, it becomes necessary to heat the product at each pumping station to facilitate its progress. Unlike a railroad, the pipe-lines, in general, follow a direct course, uphill and down.[2] The pipe-line facilities of the country are ample to handle the normal distribution of the current production.[3]

The significance of the pipe line in the development of the petroleum industry has been great. It has made crude petroleum independent of the railroads[4] and through cheapness of operation has lowered the cost of petroleum products; it has freed the refineries from geographic allegiance to areas of production and permitted their establishment at strategic points in respect to consumption of products; it has permitted and induced integration of activities, with marked advantage to the consuming public, but not unaccompanied by hardships and abuses falling upon small units of the industry itself; and by stretching out to meet a growing area of exploitation it has unified widely separated fields and enabled production to grow to its present imposing size. The pipe line has woven the scattered strands of adventurous exploration into a steady flow of bulk raw material. (See fig. 4.)

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[1] The approximate mileage of the principal pipe lines of the United States is listed in Committee Print of Departmental Reports on H. R. 3232 and S. 2812, House Committee on the Public Lands, 1918, and sums up to 28,995 miles. The total length of all the pipe-lines is much greater.

[2] An 8-inch pipe weighs 28 pounds per foot, and its cubic capacity is about 328 barrels of oil a mile. This means that millions of barrels of oil are required merely to keep the pipe-lines of the country active. The cost of an 8-inch pipe-line, on the basis of the costs of materials in California in 1914, is upwards of $20,000 a mile. (See Report of the Committee on Petroleum, California State Council of Defense, by Thelen, Blackwelder, and Folsom, July 7, 1917, which represents a detailed and valuable study of the petroleum industry of California.)

Pipe-lines are found in foreign oil regions as well as in the United States. In the Caucasus a line connects Baku with the Black Sea, 550 miles distant, passing through a rugged and broken mountainous district. At Tuxpam, one of the oil ports of Mexico, pipe-lines reach out under water for more than a mile, permitting ships at safe anchorage to be loaded.

[3] The maximum daily capacity of the principal pipe-lines, as listed in Committee Print of Departmental Reports on H. R. 3232 and S. 2812, House Committee on the Public Lands, 1918, sums up to 1,908,750 barrels, over twice the daily production of the country.

[4] A very important feature under present conditions, bringing up an obvious comparison with coal, which needs a like emancipation, at least in part. (See Bulletin 102 of this series, parts 4 and 5.)

Some crude petroleum is transported in tank cars, but most of the 60,000[1] tank cars in operation in this country are engaged in moving petroleum products—gasoline, kerosene, and fuel oil chiefly. For transportation by sea, steel tankers and towing barges, fitted with noncommunicating compartments, are employed for both crude petroleum and its bulk products. The development of the tank steamer has been an important factor in building up an important foreign trade in petroleum products, is responsible for a considerable coastwise movement of crude and fuel oil,[2] and has opened the oil fields of Mexico to the United States and other markets.

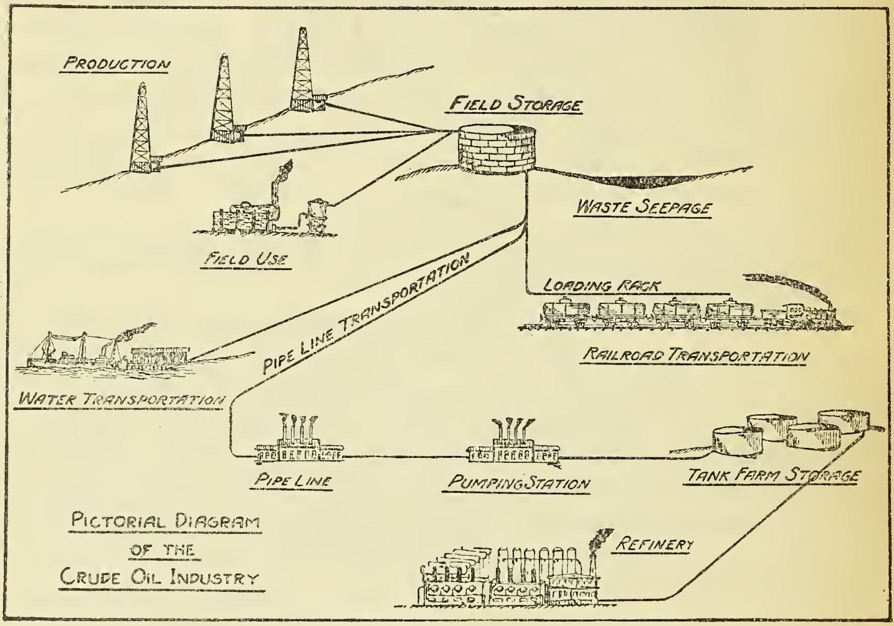

FIG. 4.—DIAGRAM OF THE CRUDE PETROLEUM INDUSTRY. FROM REPORT OF THE COMMITTEE ON PETROLEUM, CALIFORNIA STATE COUNCIL OF DEFENSE.

REFINING.

Crude petroleum may be burned as fuel and nearly a fifth of the domestic consumption is utilized in this way.[3] But most of the petroleum is manufactured into a series of products which have wider

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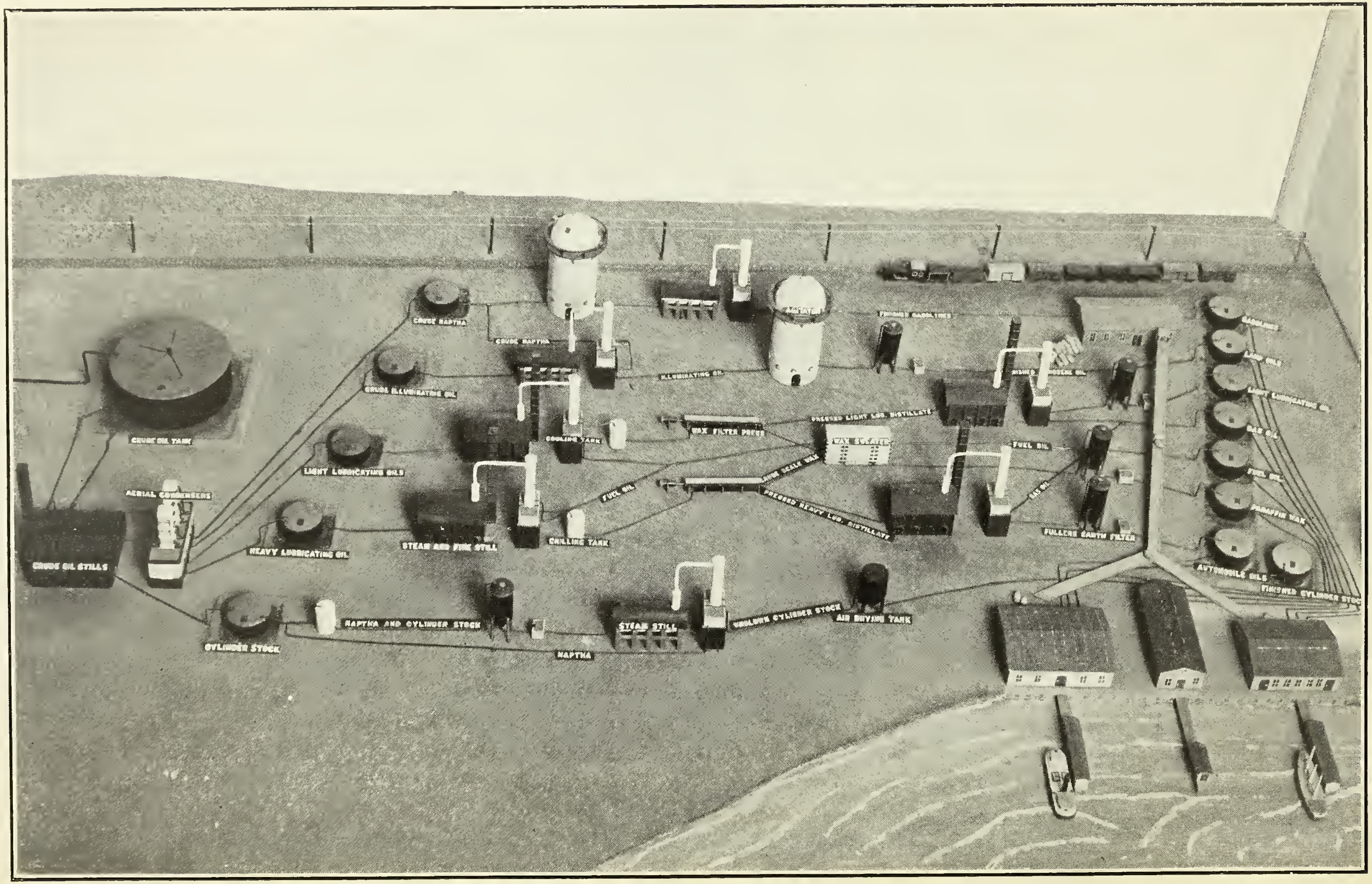
[1] Approximate number.

[2] The tanker is the only commercial rival to the pipe line; movements of oil from the Gulf to North Atlantic ports, therefore, normally go coastwise instead of overland.

[3] A small proportion of the crude petroleum is used for dressing roads.


CRUDE OIL TANK
CRUDE OIL STILLS
AERIAL CONDENSERS
CRUDE NAPTHA
CRUDE NAPTHA
CRUDE ILLUMINATING OIL
LIGHT LUBRICATING OILS
HEAVY LUBRICATING OIL
STEAM AND FIRE STILL
CYLINDER STOCK
NAPTHA AND CYLINDER STOCK
NAPTHA
STEAM STILL
AIR DRYING TANK
COOLING TANK
CHILLING TANK
FUEL OIL
ILLUMINATING OIL
WAX FILTER PRESS
PRESSED LIGHT LUB. DISTILLATE
PRESSED HEAVY LUB. DISTILLATE
FUEL OIL
GAS OIL
FULLERS EARTH FILTER
LIGHT LUBRICATING OIL
GAS OIL
FUEL OIL
PARAFFIN WAX
AUTOMOBILE OILS
FINISHED CYLINDER STOCK

Model of an Idealized Petroleum Refinery in the Division of Mineral Technology, United States National Museum.

From data supplied by Tidewater Oil Company.

usefulness and higher value than the crude oil, and it is upon this dominant part that the petroleum-refining industry depends. The refinery is merely an ingenious mechanical device whereby the raw material, through the agency of physics and chemistry, is fitted into the needs of society. As these needs are ever increasing in size and diversity, refining practice is in continuous flux, adapting a constant substance to a shifting and widening demand.

At the present time petroleum yields, when completely refined, four main products—gasoline, kerosene, fuel oil, and lubricating oil [1]—and a large number of by-products,[2] of which benzine, vaseline, paraffin, road oil, asphalt, and petroleum coke are well-known examples. Most of these products in turn may be broken up into other substances, each the starting point of further refinements. Under present practice petroleum yields only a few hundred substances of commercial value, but the mind can set absolutely no limit to the number of useful materials that chemical research may still wrest from this raw material.

While refinery practice is a highly technical matter and varies both according to the chemical nature of the oil and the local demand for products, we may, for the sake of simplicity, ignore all details,[3] and note merely that there are three main types of refineries. The first of these is called a "skimming" or "topping" plant, because the light oils, gasoline and kerosene, are removed from the rest of the products, which are left behind as a residual oil and sold in this semicrude condition for fuel purposes. The "skimming" plant, as its name implies, makes an incomplete recovery of products, supplying only those in greatest demand or easiest to make; most of the plants of this kind are situated west of the Mississippi River.

The second type of refinery may be termed the "straight-run" plant; this produces all four of the main products—gasoline, kerosene, fuel oil, and lubricating oil—together with by-products, the process separating the crude oil into its natural components with the minimum of chemical change. The "straight-run" refinery lacks flexibility, because it has no power of producing, for example, more gasoline than the crude oil naturally contains.[1] Such plants are situated in the East and other parts of the country where the demand, especially for lubricants, justifies the expense of the practice.

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[1] These are commercial terms and therefore carry no exact meaning in a chemical sense. They are used throughout this paper with their usual rough significance. Since the products merge one into the other, there can naturally be between them only an arbitrary line of demarcation. As this line has not been precisely fixed, either by commercial usage or by legal standardization, the terms are merely broad expressions of the main fractions into which the crude oil is broken. Gasoline, as here used, covers those products of crude oil which are more volatile than kerosene; the term therefore embraces some benzine and naphtha. Kerosene, as here used, is the common type of illuminating oil representing the distillate heavier than gasoline, but lighter than fuel oil. Fuel oil is used as a broad term, including all distillates heavier than illuminating oils and lighter than lubricating oils; it includes so-called gas oil—a high-grade fuel oil used in the manufacture of gas—as well as fuel oil proper, used largely for steam raising. The term lubricating oil includes a variety of heavy oils used for lubricating purposes.

[2] The term by-product has no exact meaning, though its significance is clear. For an economic discussion of this matter, consult page 67 of this paper, and Lewis H. Haney, Gasoline prices as affected by interlocking stock ownership and joint cost, Quart. Journ. Econ., vol. 21, pp. 648–655.

[3] Such details may be found spread over dozens of pages in standard treatises, such as Bacon and Hamor, The American Petroleum Industry, New York, 1916.

The third type of refinery is of recent birth, but has made rapid strides toward a great future; it employs the so-called "cracking" process, which yields, like the "straight-run" plant, a full set of products, but a greater percentage of gasoline than the crude oil gives upon ordinary distillation. This is accomplished at the expense of the heavier component oils, whose molecules are broken or "cracked" into lighter molecules, which constitute just so much additional gasoline. It is obvious that cracking has developed in response to a growing demand for gasoline; its significance is apparent in the fact that it permits the production of a more valuable product from one less valuable. With an increasing call for gasoline and a decreasing supply of petroleum, cracking may be called the hope of the future as regards refinery advance.

If we pause for a moment to contemplate the consumption of petroleum in the crude condition, and then the three types of refining—skimming, straight-run, and cracking—it becomes evident that each treatment represents a step in advance over the preceding, and that, while all four prevail to-day, the cracking refinery is in line with true progress and will eventually dominate the situation.

Refineries, whatever the type, employ the principle of distillation in their operations. The petroleum is heated in stills and the products vaporize, pass off, and are condensed in fractions, representing roughly the materials in demand. These products are then purified by chemical treatment or transformed by chemical means into a series of secondary products. The production of the various kinds of lubricating oils needed for diverse uses represents an intricate, yet single, part of petroleum refining; and is merely one aspect of the many ramifications found in refinery technique. The refining of petroleum makes heavy drafts upon other chemical industries—for example, in normal times, about one-tenth of the sulphuric acid produced in the United States goes into petroleum refining—but the refinery in turn contributes many essential products to other chemical manufacturing activities. These industrial interrelationships, ofttimes overlooked, are of the utmost significance—a fact strikingly brought out when one activity is called upon to expand more rapidly than some other activity with which it is geared.[1]

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[1] Such statements are true in a broad way only; the reader will understand that rigorous scientific accuracy of statement must be partly sacrificed to gain simpleness of expression.

The refining of petroleum, requiring elaborate plants, is by nature a large-scale enterprise; hence such activities in the main have naturally come under the control of a few large organizations.[2] While several hundred individual refineries are in operation, the bulk of the output is due to the efforts of less than 10 companies. The refining of petroleum, therefore, is largely an integrated activity, in close alliance with transportation of crude, on the one hand, and distribution of refined products on the other. It has already been pointed out that the development of pipe-line transportation has permitted the establishment of refineries at points distant from oil fields, but convenient to centers of consumption and to seaports. Hence one of the largest refineries in the world is at Bayonne, N. J., consuming oil from the interior of the country.

With the broad outlines of refinery technique in mind, it will be of interest to observe the shifting focus of development that has characterized the production of petroleum products in America. When the famous Drake well struck oil on Oil Creek, Pa., in 1859, an illuminating oil distilled from coal and called " coal oil " was in general use throughout the country. Petroleum, therefore, found a market already established for its illuminating constituent, which it usurped at once, quickly supplanting the coal-oil industry with a production of *kerosene*.[3] Although other products were also produced and lubricating oils made from petroleum found quick favor in connection with a growing application of mechanical energy, kerosene became the chief petroleum product and for over 40 years its use expanded until this illuminant penetrated literally to the uttermost corners of the globe. It would be difficult, indeed, to estimate the value to the world at large of this cheap and convenient source of light, which has been aptly termed " one of the greatest of all modern agents of civilization."[4] During this period there was little demand for the light products of distillation, the liquids now sold under the commercial name of gasoline, which were, therefore, largely waste products in an economic sense and even in some instances physically destroyed for want of any adequate demand for their utilization. Gasoline for a long time, then, was a by-product of little value turned out in the manufacture of kerosene. (See fig. 5.)

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[1] The apparent failure to recognize and allow for this fundamental principle has been the source of considerable trouble in connection with recent production aspects of the industrial situation in the United States.

[2] Small plants can not focus on refinements of development, hence they mean resource waste.

[3] To this day the term " coal oil " is not uncommonly, though incorrectly, applied to kerosene. Crude oil itself was not adapted to illuminating purposes, but the fact was quickly discovered that a satisfactory oil could be distilled from it; and with the establishment of that fact a great industry was safely launched.

[4] "All the world loves light, which is so necessary for the reading habit and the spread of civilization, and kerosene made from petroleum is, in every continent, the most common illuminant for the family lamp. For ages mankind had been depending upon vegetable and animal oils. Since remote times the lamps of south Europe have been lighted with olive oil. In northern Europe and America whale oil was more popular, but by the middle of the nineteenth century the demand for this oil had become so great that the whales were well nigh exterminated, and the discovery of abundant petroleum and the art of using it came just in time to prevent a return to the gloom of the tallow candle." J. Russell Smith, Industrial and Commercial Geography, 1913, p. 404.

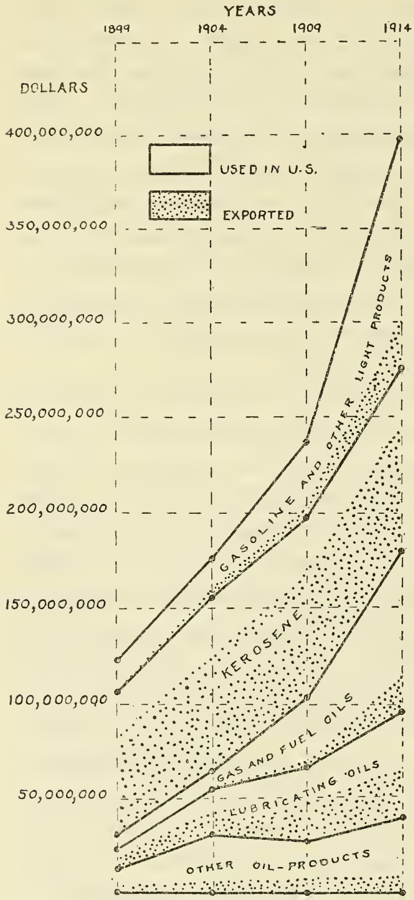

Fig. 5.—Chart showing the relative values of the principal petroleum products manufactured in the United States from 1899 to 1914. Note the decreasing importance of kerosene in sustaining the cost of refining, and the necessity of exports for maintaining a balanced outlet of products. Data from Story B. Ladd, Petroleum, Refining. Census of Manufactures: 1914, Bureau of the Census, Washington, 1917, p. 10.

Toward the close of the nineteenth century, however, the commercial application of the incandescent mantle in gas lighting and the development of the electric light introduced a type of illumination so superior to the kerosene lamp in convenience that the use of the latter was gradually relegated, in large part, to the small town, the country, and foreign regions, where the introduction of gas and electricity was not possible. Accordingly, in spite of a most aggressive campaign for foreign trade on the part of the petroleum industry, the refinery faced the restrictions of a slowing demand for kerosene which presaged a limit to the output of the whole set of petroleum products. But the menace of this limiting circumstance was destroyed, before it became effective, by the introduction and rapid advance of the internal-combustion engine. The phenomenal growth in the use of the automobile built up such a heavy demand for gasoline that this product came into the lead and took up the burden of justifying the increasing refinery consumption of crude petroleum—a burden which kerosene, even with the aid of a growing market for fuel oil, lubricants, and other oil products, was scarcely longer able to sustain. Gasoline now is the main prop to the whole cost structure of petroleum refining.[1]

With the industrial quickening due to the entrance of the United States into the world war, the demand for fuel oil[2] has become so insistent that the complexion of the oil situation has again changed and the emphasis now falls upon fuel oil. And as the production of crude petroleum has not been able to keep pace with the attempted consumption of fuel oil, a serious shortage of this product has resulted; even while the supplies of gasoline have been ample to maintain the activities of war, business, and pleasure.[3]

If the course of development, as indicated by this broad survey of refinery evolution, be projected into the future, we may foresee a time when the petroleum industry will yield a range of fuels for the internal combustion engine only; illuminating kerosene in quantity narrowing to that desirable for country use and export trade; lubricating oils adjusted to the growing demands of mechanical power; and an ever-widening range of chemical products supporting a great oil by-products industry, rivalling if not exceeding the coal-products industry in importance. In respect to the last, it should be emphasized that the United States to-day faces an opportunity similar to that which 20 years ago confronted both Germany and the United States as regards the manufacture of dyestuffs, explosives, fertilizers, drugs, and other chemicals from the nonfuel components of coal.

DISTRIBUTION.

Many industries terminate their activities with the manufacture of commercial products, turning these over to independent agencies for distribution. With the petroleum industry, however, distribution forms an integral division of the industrial activity, a carefully planned out construction of markets as part of the resource development being substituted for a demand ordinarily left to natural growth or maintained by costly advertising. Thus, once the oil is produced, it passes through the various stages of transportation, refining, and distribution under the influence of a highly organized economic machine, a coordinated industrial unit, engaged not merely in adapting a crude material to diverse uses, but also in shaping and developing latent needs the world over into a demand which will sustain a balanced output of products.

We have already seen how the pipe-line, and to a less extent the coastwise tanker, brings the crude petroleum to the refineries which are favorably located in respect to distribution. From the refineries the gasoline, kerosene, fuel oil, lubricating oil, and other petroleum products are sent forth to supply the needs of surrounding territory, while refineries near seaboard furnish heavy contributions to foreign trade. As distribution is a diverging process, and, moreover, the crude petroleum is broken into numerous products requiring separate handling, the pipe-line is not broadly adapted to this diverse haulage. Railroad tank cars,[1] therefore, receive the bulkier products and carry them to distributing depots, where storage tanks release the railroad carriers and supply tank wagons that radiate to fill the local needs. In this way the entire country is covered by a network of specialized transporation, each step employing a bulk carrier best adapted to its particular purpose both as to size and mechanical facility, the whole involving the maximum of expedition and simplicity. Without this highly organized system, with its far-reaching ramifications, the present widespread use of gasoline and kerosene would not be possible. From the oil field to the consumer, the handling of petroleum is remarkably efficient.

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[1] For an interesting discussion of this matter, see Report on the price of gasoline in 1915, Federal Trade Commission, 1917, pp. 52–53.

[2] The demand for fuel oil has been accentuated by an inadequate coal supply and is in part a reflex from that circumstance.

[3] Various aspects of this situation will be treated in the section on the war situation, pp. 35–39 of this paper.

The arrangements whereby a foreign trade has been built up and sustained are no less elaborate. Fleets of tank steamers and freighters carry the products in bulk or in suitable containers to all parts of the world. Fuel oil, gasoline, and lubricants go in greater measure to industrial countries, but kerosene penetrates to every corner of the globe, a system of depots and distributing lines adapting the product to the needs of the most out-of-the-way regions. The care that has been bestowed upon the extensions of the market for kerosene, against every conceivable obstacle of climate, topography, and racial prejudice, is a striking example of industrial foresight; yet without this policy, the whole oil industry would have been unable to expand to its present proportions.

THE NATURAL GAS INDUSTRY.

Natural gas is produced in large quantities in the United States, partly as a by-product from oil wells and partly from gas wells drilled in oil fields or adjacent territory. Both natural gas and petroleum are of common origin, the former indeed being merely a volatile component of petroleum, occurring either dissolved in the petroleum under pressure or migrated, as result of the advantageous degree of mobility favoring a gas, to positions more or less distant from the petroleum. The gas-bearing territory of the United States, therefore, embraces the productive oil fields and a considerable area besides. (See fig. 2.) Natural gas is won in 23 States, of which West Virginia, Pennsylvania, Ohio, and Oklahoma enjoy the largest commercial yields.

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[1] And to some extent barges where water transportation is advantageously available.

The natural gas produced is of two types according to whether it carries a conspicuous burden of gasoline vapor or is lean in this constituent. The first type, as may be surmised, flows from an oil-productive stratum and is called "wet" or casing-head gas, since it makes its appearance from the casing-heads of oil wells. The second type is termed "dry" gas, and comes from portions of porous rock formations practically free from oil; it is produced through gas wells more or less independently of petroleum output.[1]

While not vital to the country, because its use may be supplanted by other types of fuel, natural gas is of considerable commercial importance, as shown in the accompanying table:

Relative commercial importance of natural gas, expressed on a per capita basis for 1915.[a]

	Consumption per capita.	Value per capita.	Average price.
Natural gas (cubic feet)	[b] 6,285	$1.01	[c] $0.16
Artificial city gas (cubic feet)	1,818	1.65	[c] .91
By-product, coke-oven gas (cubic feet)	840	.08	[c] .10
Crude petroleum (barrels)	2.8	1.79	.64
Anthracite coal (tons)	.9	1.84	[d] 2.07
Bituminous coal (tons)	4.4	5.02	[d] 1.13

[a] Figures calculated on basis of population of 100,000,000 from data published in Mineral Resources of the United States for 1915, U. S. Geological Survey.

[b] Includes various types of artificial gas as commonly supplied in municipalities.

[c] Note the marked discrepancy in price. The intrinsic value, as contrasted to the commercial value, is 1.5–2, 1, and 1 respectively.

[d] Price at mines.

About one-third of the natural gas consumed in the United States is used for domestic purposes—lighting, cooking, and heating—while about two-thirds is burned in industrial plants under steam boilers and especially in metallurgical operations, glass and pottery furnaces, and cement kilns, where the requirements of an intense heat call for gaseous fuel. In Ohio and Western Pennsylvania, in particular, the abundant occurrence of natural gas has determined the location and widespread development of gas-fired industries.[2]

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[1] The two types of gas are gradational, not sharply distinctive. "Wet" gas carries upwards of three-fourths of a gallon of gasoline per 1,000 cubic feet of gas, while much of the "dry" gas carries only from one to two pints of gasoline per 1,000 cubic feet. See George A. Burrell and others, Extraction of gasoline from natural gas by absorption methods: Bulletin 120, Bureau of Mines, 1917.

[2] Thus Ohio and Pennsylvania are the two leading States in the manufacture of clay products; the Pittsburgh district is the greatest glass-manufacturing district of the United States, while the iron and steel industry in the vicinity of Pittsburgh consumes an enormous volume of natural gas in its blast furnaces, foundries, and rolling mills. Natural gas has been "the fourth element in making western Pennsylvania more liberally supplied with fuel than any other place in the world. In that region a thick forest covered hills which were underlain with the magnificent coal deposits of the Appalachian field, while farther down was the crude petroleum and the natural gas that drove it spurting from the orifices in the rocks." The rising cost of natural gas, coming with progressive exhaustion of fields, has caused a migration in the glass-making industry, many plants having moved from Pennsylvania to West Virginia and from Indiana to Oklahoma in order to get cheaper fuel; other plants in regions de-

Those activities concerned with the production, transportation, and marketing of natural gas constitute the natural-gas industry. It is largely independent of the petroleum industry, although partly overlapping in production. It consists, in the main, of a large number of independent companies in the form of public-service corporations, although some oil companies market their surplus gas. The drilling of gas wells is not essentially different from that of oil wells; but gas, unlike oil, can not be stored in the field and hence is piped directly to centers of consumption. The gas emerges from new wells under high pressure,[1] but as this declines within a comparatively brief period, the gas field is equipped with compressors which serve to increase the speed and volume of the gas that may be transmitted through gas pipes to distributing stations.

The wastes in natural gas have been appallingly great in the past, and even now, with some of the most glaring points of wastefulness corrected, the resource recovery, by and large, is notoriously small. In connection with the production of oil, especially in fields distant from markets, there has been little incentive to bother with the gas, which has largely been looked upon and treated as a waste product, although now known to be necessary to the proper recovery of the oil. By means of mud-laden fluid, the gas-bearing beds encountered by the oil-seeking drill may be sealed off and the gas conserved for the protection of the oil beds and for subsequent recovery. The gas flowing from the oil-productive stratum along with the oil, particularly in the gusher and youthful period of production, is the casing-head gas from which, since 1910, a growing production of gasoline has been won.

In the gas fields proper, which produce the bulk of the natural gas supplied to cities, the physical wastes which once prevailed have largely been alleviated by correct practice, but there is still economic loss, felt in prospect by the communities concerned, resulting from the circumstance that small leaseholds and competing wells force hasty extraction. This contributes to a general overproduction, leading to an offering of the surplus gas to industrial plants at low rates in competition with coal. Thus, in 1915, the average price of natural gas to industrial users was 10 cents for each 1,000 cubic feet, as contrasted with the average rate of 28 cents charged domestic consumers, a figure none too high as compared with an average rate of

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clining in natural-gas yield have turned to producer-gas made from coal, a less satisfactory fuel because not so high in heat value. (See The Glass Industry, Miscellaneous Series No. 60, Bureau of Foreign and Domestic Commerce, 1917, pp. 187–188.) The manufacture of carbon black, or lampblack, used in pigments is an industry almost confined to West Virginia, where in 1915 from 19,000,000,000 cubic feet of natural gas there was manufactured 17,000,000 pounds of carbon black, the gas for this purpose having an estimated average value of 2.34 cents per 1,000 cubic feet.

[1] In some instances the pressure is so high, upwards of 1,000 feet to the square inch, that it has to be reduced before piping. In general the pressure of casing-head gas is much lower than that of "dry" gas.

91 cents[1] for artificial city gas scarcely half as good. Since natural gas is the cheapest and most convenient fuel for the home, it seems unfortunate that the limited supply should be squandered for purposes for which coal would suffice.

A full utilization of oil-well gas is dependent upon the course of progress in oil production, as the waste in this connection is merely part of the inferior utilization characterizing the petroleum resource. The proper utilization of "dry" gas, however, involves the elimination of haste-forcing competition among the natural gas companies, which can only come from the control of gas fields by large, well-integrated units, so as to obviate the current overproduction which supports an undue industrial use in regions amply supplied with coal.[2]

While the production of gasoline from natural gas has been largely confined to casing-head gas, because of its relative richness in gasoline vapor, the recent development of absorption processes extends the possibility to the bulk of the "dry" gas produced. It is conservatively estimated that a gasoline production of 100,000,000 gallons a year could probably be attained in this manner, and a significant start is already under way.[3]

3. THE LIMITATION.

We have examined briefly the character and occurrence of petroleum and reviewed in broad outline the industrial activity engaged in the exploitation of this substance. With the magnitude and importance of the petroleum industry in mind, it becomes desirable to observe the portion of the resource not yet used in order to measure its capability toward sustaining a growing responsibility.

THE PETROLEUM RESERVE.

While unmined petroleum, like other mineral resources not exposed to sight, can not be inventoried with a nicety of exactness, the proven and prospective oil fields of the United States are, nevertheless, so broadly known that the petroleum reserves may be estimated within a very reasonable margin of error.[4] This has been done by the

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[1] The price of artificial city gas is much higher than it need be in a revised system of fuel utilization. See Bulletin 102, part 4, this series. The cheap supply of natural gas offered industrial users has been one of the factors retarding an effective market for by-product coke-oven gas, thus hindering to a certain measure the adequate development of a coal-products industry in this country.

[2] Natural gas production under cooperative or organized control could render a more distinct service in emergencies such as the present than it is capable of under current conditions. As a war measure natural gas must be ruthlessly sacrificed as a reserve brought to the aid of coal; but such service should be distinctly temporary.

[3] See George A. Burrell and others, Extraction of gasoline from natural gas by absorption methods: Bulletin 120, Bureau of Mines, 1917.

[4] Few, other than engineers, realized the extent and accurateness of the data bearing on mineral deposits which the rigorously scientific methods of the United States Geological Survey have collected.

United States Geological Survey and the accompanying table shows in simplified form the balance sheet as it stands at present:

Petroleum reserve of the United States, calculated[a] *to a per capita basis.*

	Per capita rate of production (1917).	Mined to date, 1859-1917.	Now underground (1918) and available under present methods of mining.
Petroleum	3.4 barrels	42 barrels	70 barrels.

[a] The figures are given in round numbers based on a population of 100,000,000 and are calculated from data presented by the Secretary of the Interior in Senate Document No. 310, 64th Congress, 1st session, Feb. 3, 1916, p. 17, which take into account "the productive possibilities, not only of pools already demonstrated to contain oil, but also of those untested areas in which the geologic evidence is promising."

It is evident from the foregoing table, based on the accumulated knowledge of hundreds of workers in petroleum geology, that an imposing proportion of the petroleum supply is used up. But this table does not tell the whole story; the consumption of petroleum, to say nothing of population increase, is growing from year to year at a strong rate, so that a continuation of the present tendency would exhaust the petroleum remaining in an alarmingly short period of time.

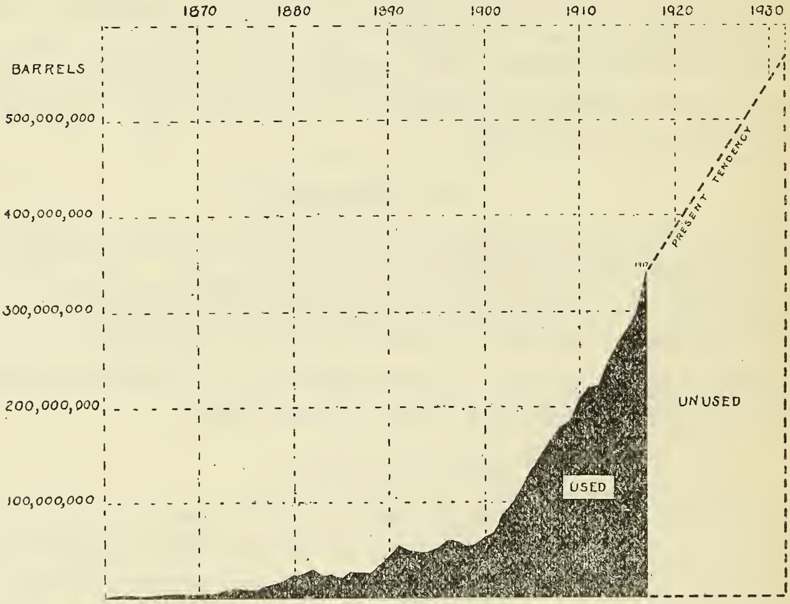

Fig. 6.—Chart showing the present tendency of the United States in respect to its unmined reserve of petroleum. Data from U. S. Geological Survey.

This aspect of the situation is depicted graphically in figure 6. With no pretense to prophecy, the diagram expresses the situation that faces the country to-day, and the most generous allowance of margin to cover possible underestimates of future discoveries does not change materially the nature of the issue. A big fraction of the domestic petroleum is gone; whether that fraction is one-third, as present knowledge indicates, or is one-fourth or even one-fifth, makes no difference in the consideration demanded by the situation. The fact remains that the size of the fraction has meaning to people using petroleum to-day and therefore represents an economic factor that must be reckoned with now.[1]

It is, of course, very evident that the present tendency can not persist to the point of even approximate exhaustion,[2] because conditions naturally arising, such as price increase, growing imports, and others will serve to relieve the tension and thus spread the remaining supply over a greater number of years. So, in spite of its sensational character, the physical exhaustion of the petroleum resource is a theoretical matter of academic interest purely. But of practical importance is the period of economic stress that is ushered in when the resource faces a greater demand than it can fill in the customary manner. That is a period of readjustments to meet the new conditions, and arrives far in advance of physical exhaustion.

As a matter of fact, local adjustments are constantly under way, as petroleum fields reach their climax of production and pass into a period of decline. Thus each field forecasts the history of the resource in its entirety (see fig. 7). These local adjustments affect the industry in the way of causing geographic shifts in activities, but they have thus far had no national effect, because youthful fields have heretofore been ready and able to sustain the shifted burden. But obviously a limit must eventually be reached when an adequate array of youthful fields will be lacking. A consideration of the present situation, in this light, brings forth the realization that such a dominant proportion of our petroleum supply is drawn from the Kansas-Oklahoma and California fields, that their decline can scarcely expect compensation, without development of other fields to a degree to which there is no prospect. It is generally conceded, too, that these two fields have well-nigh, if not already, reached their productive climax (see fig. 7).

It would appear, therefore, that entirely apart from the size of the petroleum reserve, the dependency upon a cumulative oil-field

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[1] European countries have repeatedly faced the impending exhaustion of a resource and therefore have gained experience in handling such a situation. But this matter presents an entirely new problem to the United States, and she naturally has no built-up and tried-out machinery for solving it. The average person in this country to-day, or let us say a year ago, apparently looked upon a mineral resource (if he considered it at all) as a clay bank, inexhaustible and to be dug into at will. Consequently, to carry the figure further, our ideas of resource administration as reflected in public policy are excellent for clay-bank resources (and we have some of that kind; i. e., cement, building stone, sand, clay, etc.), but not suitable for those more limited and elusive minerals that must be wrested from the depths of the earth.

[2] It would appear that complete exhaustion could be achieved by destroying inhibiting economic conditions; that is, by means of extreme measures of socialization, such as fixing a price under a system of forced production.

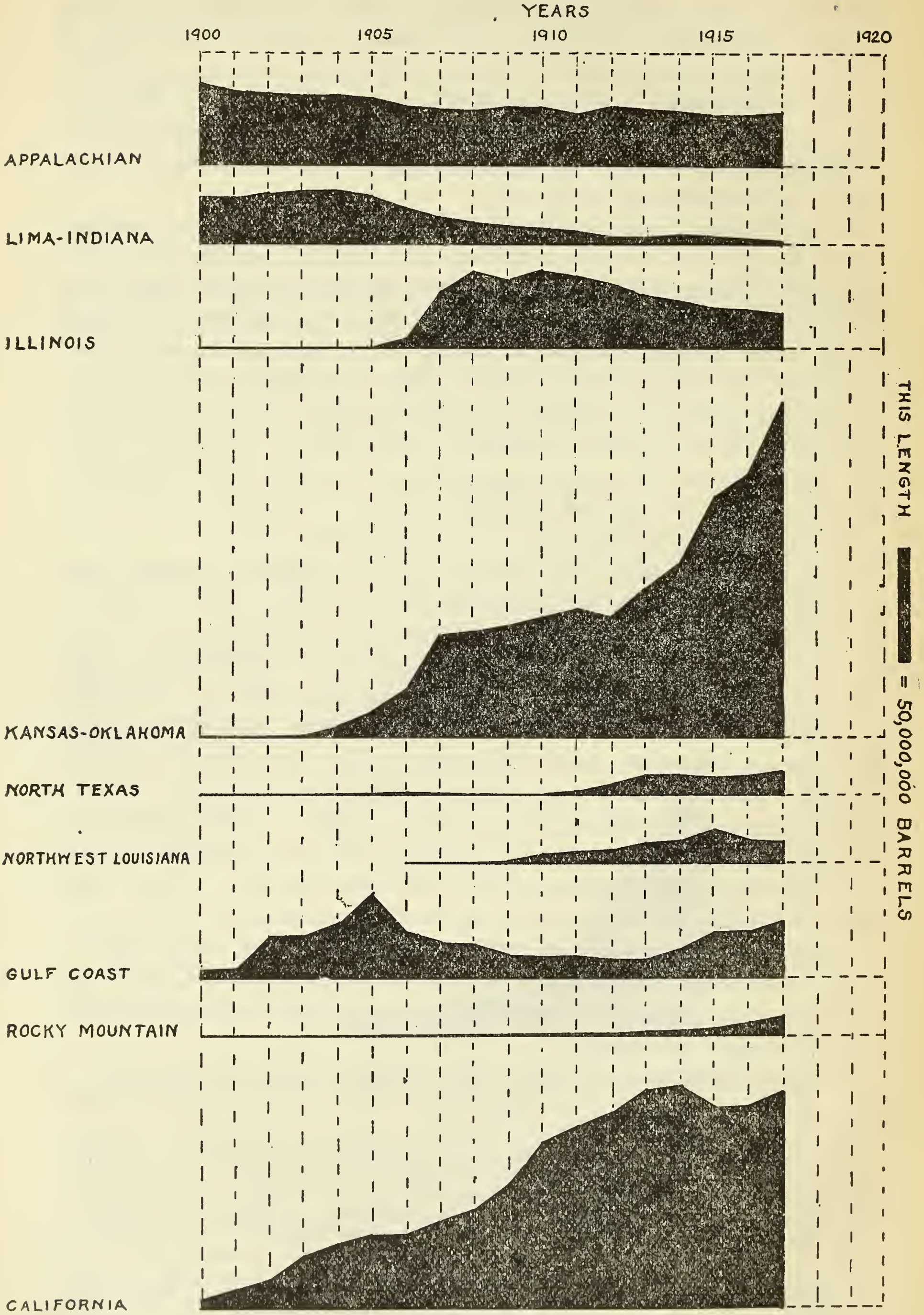

FIG. 7.—THE RELATIVE OUTPUT OF THE PRINCIPAL OIL FIELDS OF THE UNITED STATES FROM 1900 THROUGH 1917. NOTE THE DOMINANT POSITIONS HELD BY THE KANSAS-OKLAHOMA AND CALIFORNIA FIELDS. DATA FROM U. S. GEOLOGICAL SURVEY.

development presages a time, soon to arrive if not already here, when the present rate of production can no longer be sustained in its full vigor. Just so soon as the aggregate output is compounded of senile and youthful fields, with the latter no longer in the ascendency, the resource as a whole will pass inevitably into a period of slowing and more costly production, even though the resource is yet but half exhausted.[1] The period of economic stress, then, waits merely on this concatenation of circumstances, by no means upon a marked physical exhaustion of the resource.

WHAT PETROLEUM EXHAUSTION MEANS.

It appears from the foregoing section that the petroleum resource is not only strictly limited in size but also in ability to sustain the present rate of increase in production. We may examine, then, what would be involved in a curtailment of activities dependent upon petroleum, since this necessity lies in prospect, in order to be better prepared to weigh the gravity of the issue.

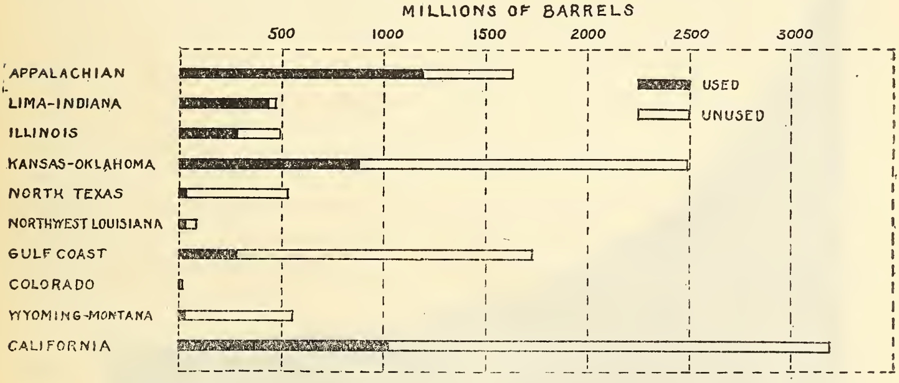

FIG. 8.—CHART SHOWING THE APPROXIMATE DEGREE OF EXHAUSTION OF THE PRINCIPAL PETROLEUM FIELDS OF THE UNITED STATES. THE "UNUSED PORTIONS" CAN BE GREATLY INCREASED BY RECONSTRUCTED METHODS OF PRODUCTION. DATA FROM U. S. GEOLOGICAL SURVEY.

As already noted, crude petroleum[2] is converted into four main products—gasoline, kerosene, fuel oil, and lubricating oils—and a group of substances less consequential at present which may be termed by-products. The social importance of these five classes of products may be examined in turn, although some of the points have been intimated earlier in this paper and much of the matter is so universally familiar as scarcely to require even summary treatment. For the latter reason, emphasis will be placed not so much upon the importance of these products as indicated by the past or even the present, as upon their potentialities which the course of affairs are bound to bring out, granted a continued supply. This, in point of fact, is the fairer method, for we are trying to measure off the future significance of petroleum products against the impending inadequacy of the resource.

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[1] An oil field in its youth is vigorous; then, in particular, gushers pour forth their exuberance. Later, in maturity and with increasing age, the production is maintained with growing difficulty; many more wells must be drilled; the oil responds less willingly to stronger pumping. Eventually the production declines long before the field is near exhaustion. The gasoline content of the oil also decreases, as a rule, with the aging of the field or pool.

[2] Apart from the one-fifth, more or less, used in the crude condition, which falls largely into the class of fuel oil.

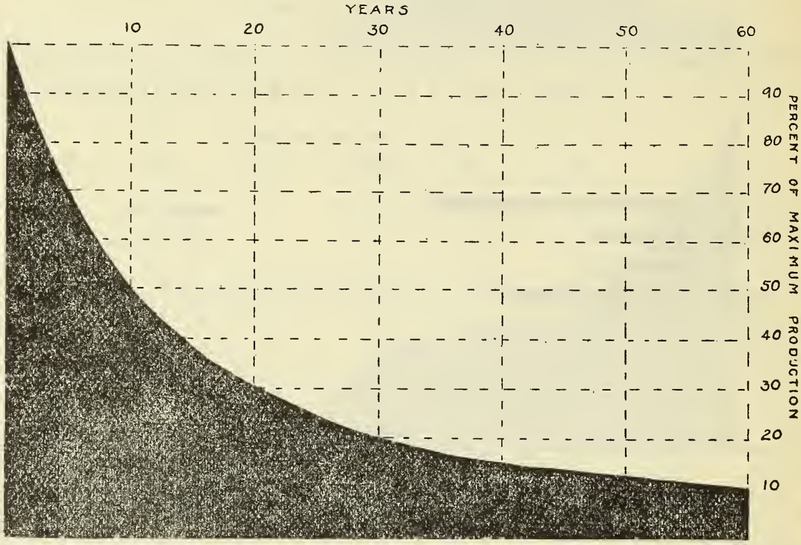

FIG. 9.—CURVE SHOWING THE USUAL DECLINE IN OIL-FIELD PRODUCTION AFTER THE PERIOD OF MAXIMUM OUTPUT IS REACHED. AFTER RALPH ARNOLD, THE PETROLEUM RESOURCES OF THE UNITED STATES, SMITHSONIAN REPORT FOR 1916, P. 283. COMPARE THIS THEORETICAL CURVE OF FINAL DECREASE WITH THE PRODUCTION CURVES SHOWN IN FIG. 7.

Gasoline is responsible for the most significant mechanical development of the twentieth century—the internal-combustion engine.[1] The growing use of this device for generating power, with its great efficiency and adaptability to small movable units, such as the automobile, has colored the whole face of modern civilization. Because of it, a wholly new type of automotive transportation has grown up, at a time when the long-established methods of cumbersome, coal-energized haulage were beginning to impose a serious restriction upon the growth of industrialism and centralization.[2]

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[1] Unless, indeed, the internal-combustion engine has been responsible for the development of gasoline! As a matter of fact, this type of engine was well known before 1900, although its growth has been most striking during the past 18 years.

[2] The electric motor, of course, has shared with the internal-combustion engine the credit of partly freeing transportation from the restrictions inherent in the necessity for hauling the source of its energy in bulky form. Further turns of this important consideration are followed in Bulletin 102, part 5, of this series.

The automobile, of course, first by its novelty and later by its wide appeal, has been the prime mover in the automotive development. It would appear to be unnecessary to particularize as to the social value of the automobile, as this matter is common experience. It may be said, however, that apart from its purely luxury use, with which we are not here concerned, the automobile has served to enlarge the possibilities of modern life, not merely by contributing pleasure, but in improving opportunities for physical and mental recreation, social contact, and business activity, with no small contribution toward facilitating the livableness of the modern city. The automobile has gone far on the road toward solving the problem of personal transportation.[1]

An important outgrowth of the automobile development has been the motor truck, now used in great numbers for city and suburban delivery service, and coming into prominence in the more populous country districts as an efficient agent for short-haul freight. The importance of this matter is suggested by the fact that the motor truck in 1917 hauled over 60 ton-miles of freight for each person in the United States.[2] The possibilities of the motor truck are still largely unrealized; its continued extension may be expected to replace largely the short spur line of the railroad; and in connection with the growth of a network of good roads, a country-wide auto-truck utilization will furnish an efficient feeder system to the trunk transportation channels of the country. In respect to the prompt delivery of farm produce, whether to railways or directly to towns, the motor truck has an exceptionally useful opportunity.[3] The whole problem of food supply, indeed, is closely bound up with the matter of adequate facilities of transportation[4] and appropriate use of mechanical power, for both of which petroleum products have a tremendous field of unrealized usefulness.

The tractor for farm use is a still more recent development than the motor truck and the growth in its utilization during the past few years, especially in the Middle West, has been great. Coming into play at a time when the national food problem has taken on a world-wide aspect, the tractor assumes the utmost present importance, while the future demands an extension in its use such as may be expected to largely relegate to the past the old-fashioned methods of hand-power and horse-power tillage. Indeed, upon the growing use of mechanical power upon the farm by means of the tractor, the motor truck, the stationary engine, and the automobile—all dependent upon a cheap and adequate supply of motor fuel—the food supply of the future turns. Farm work must be made more agreeable and more efficient if a growing population is to be fed.[1]

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[1] It is scarcely necessary to point out that the automobile supplements, but does not replace, the standardized service rendered by the steam passenger train and the electric urban and interurban lines.

[2] This was only a small fraction of the freight hauled by the railroads of the country, whose record in 1915 was 2,768 ton-miles per capita, yet the proportion is important and growing.

[3] The horse and mule for small-unit haulage are destined to pass in large measure; they represent an engine consuming high-priced fuel useful otherwise as food, running 24 hours a day whether used or not, and low geared with a capacity of only 3 to 4 miles an hour at best.

[4] The problem of good roads has never received adequate attention in the United States. A striking example of the intricate interrelationships of industrial problems is afforded by the fact that good roads in part rely upon the use of road oil, which is made both from petroleum and from coal tar, being thus dependent upon the adequacy of the petroleum-products industry and the coal-products industry.

The present importance and future significance of the stationary internal-combustion engine, the motor boat, and the airplane need scarcely be touched upon here. As to the last, its use in the present war has led to such a development in flying technique as to justify the expectancy that this speedy and mobile agent will soon come into a growing measure of service and use in the affairs of civil life.[2]

Back of the widespread utilization of the internal-combustion engine stands a great industry engaged in the manufacture of automobiles, motor trucks, and tractors. Starting scarcely two decades ago, this activity has grown until it now represents the third industry, in point of financial value and importance, in the country. In 1917 motor vehicles of all kinds to the number of 1,814,988 are reported to have been manufactured in the United States, having a wholesale value of nearly $1,100,000,000.[3] As may well be appreciated, the automotive industry, by virtue of the kind and amount of labor to which it gives employment, of its ramifying sales agencies and extensive advertising, and in turn through its use of steel, aluminum, nickel, rubber, leather, wood, and other raw materials, extends its roots throughout much of the industrial fabric of the country. This industry is wholly dependent upon the adequacy of petroleum products for continued growth.

It would appear, then, that curtailment in supply of motor fuel would affect a remarkably wide range of interests. The automobile owning public, farmers, business activities using motor trucks, and the automotive industry with its ramifications—or expressed in another way, transportation, food production, and a large branch of manufacturing—all have a vital concern in this matter. Under a waning petroleum supply, these various activities would suffer a progressive narrowing in scope which would be the antithesis of the continued progress that their importance urges.[1]

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[1] This whole matter is of the utmost importance, with many complexities that can not be gone into here. The agricultural industry should be the greatest of all industries, but instead it is merely a loose assemblage of disjointed, individual activities, with a tendency in many sections to disintegrate further rather than to unify and undergo organization. With some notable exceptions, therefore, it has made little progress toward effectiveness in a broad way—the toil of the farmer is still notorious—and the Government as yet has taken few broad, constructive steps looking toward cooperative developments in farming, confining its efforts thus far largely to polishing off details in the present inadequate system. Fertilizers and tractors, under organized cooperative effort, spell the solution to the food problem—a problem which otherwise will become still more critical within a very few years, whether the war persists or not. It is a curious and pathetic anomaly that the two most basic industries in the United States, the food-production "industry" and the coal industry, are the most inefficiently organized!

[2] A modern military airplane consumes about 20 gallons of gasoline an hour. The quantity of gasoline for the American fleet in course of construction will amount to several million barrels a year.

[3] The Annalist, Jan. 7, 1918, p. 10.

In respect to kerosene, we have previously observed that this illuminant has brought a cheap light to millions of people the world over.[2] This commonplace substance has been America's greatest gift to the uncultured peoples of the globe. With the latter-day development of city lighting, however, the kerosene lamp has been displaced in civic centers, but it still remains the solace of the evening hour among the country folk of this country and the natives of nearly every foreign region. A failing supply would return much of the world to the gloom of the flickering candle, a setback that it is the altruistic duty of this country to circumvent, if consistently possible.

Over half of the petroleum currently produced is used as fuel for steam raising, this portion including the crude petroleum employed for fuel purposes and the fuel oil proper turned out by petroleum refineries. The whole southwestern portion of the United States is wholly dependent upon fuel oil; Pacific coast shipping and naval activities on both oceans draw much of their energy from this substance; and with the progress of war activities a growing number of industrial operations of the eastern half of the country are employing this convenient fuel. While the application of fuel oil to steam raising is an economic perversion, for which the penalty is severe, the fact remains that the United States is, for the time being at least, hopelessly entangled in the necessity of prolonging much of this wasteful practice, an unduly forced reduction of which would be fraught with disastrous consequences, particularly for the Southwest. The use of fuel oil, however, has grown so extensively during the past year that an overburden now rests upon it which will bring an inevitable train of industrial disasters in the coming months, as the supply is wholly inadequate to sustain even the current demand. Unfortunately, the swing away from coal in favor of fuel oil is still continuing.

As regards lubricating oils, we are confronted with the fact that the whole mechanical equipment of modern civilization is dependent upon lubricants made from petroleum.[1] For purposes of reducing friction (i. e., conserving energy), few substitutes are in sight for mineral oils;[2] vegetable and animals oils, although preferable for certain highly specialized purposes, are unsuited for general employment, as they oxidize and thicken with use, and tend to become rancid and attack the metal bearings which they cover. With the passing of petroleum, mineral lubricants will be manufactured from oils distilled from shale and from coals, according to methods in operation to-day in countries lean in petroleum, as Scotland and Germany.[3] At the present time, in the United States, petroleum is produced and manufactured into products far in advance of lubricating needs, which means that the lubricating portion of the resource is being exhausted at a rate dictated by the demand for oil for power generation. Thus the exhaustion of our principal lubricant resource is being accomplished with much greater dispatch than is justified by true necessity, since part of the fuel demand could be filled by means (i. e., coal and hydroelectricity) not involving a sacrifice of potential lubricants.

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[1] The possibilities of oil-energized automotive agencies are so great and vital that before long it will be looked upon as an inconceivable folly that oil should ever have been used for steam raising, the most glaring economic perversion that this country has ever been guilty of.

[2] Part of the kerosene produced is also used in stoves for heating and cooking, part is now used in the engines of heavy trucks, and still another part in process of manufacture is "cracked" into gasoline.

Finally, in regard to the large array of by-product substances which are manufactured from crude petroleum, it is evident that these products, which to-day have an aggregate value of scarcely 10 per cent of the total output of the petroleum industry, represent a wealth of raw materials, one step removed from the parent, which together have literally an infinite field of growth, except for limitations of supply. Apart from the present importance of oil by-products, which concern such fundamental matters as paint manufacture, road construction, food preservation, and life conservation,[4] petroleum holds out reasonable prospects of supplying in important amounts edibles, synthetic rubber, and dyestuffs at no distant date, while an intense focus of chemical research on the matter may be expected to yield a flattering return in many additional directions which now can not be wholly foreseen. The accomplishments to date of this kind in the field of coal products are already well known, although even yet the United States is not taking adequate advantage of its possibilities in this respect; oil by-products afford perhaps even a greater opportunity than stretches out from coal products, but with the difference in respect of the former that the trail is as yet scarcely blazed.[1] It would not be an exaggeration to say that oil by-products represent one of the foremost industrial opportunities that confront the American Nation to-day.

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[1] Writes M. L. Requa (Senate Doc. 363, 64th Congress, 1st session, Mar. 9, 1916, p. 5): "For it [petroleum] there is no satisfactory substitute as a lubricant; its exhaustion spells commercial chaos or commercial subjugation by the nation or nations that control the future source of supply from which petroleum will be derived. There is but one escape, and that is the discovery of some substitute, now unknown, that will as efficaciously and economically lubricate the machinery of the Nation. * * *"

[2] Roughly, one-half pint of lubricating oil is required for each ton of coal made into power. Castor oil offers interesting possibilities as a lubricant.

[3] There is reason to believe that Germany is suffering a serious shortage in lubricating oils, a dearth which she is only in part relieving by the use of oils made from the distillation products of coal. (See Nature, Jan. 24, 1918, p. 414.) Should circumstances arise under which the petroleum fields of the Caucasus are threatened, the critical bearing of this juncture, as offering to Germany the prospect of an adequate supply of lubricants and other petroleum products, should be held clearly in mind by the allied countries.

[4] The use of petroleum products in medicaments and of paraffin in treating burns are interesting examples.

In this connection an interesting vision opens up as to how a great oil by-products industry,[2] through the values accruing to successive refinements of products, may be led to contribute more than it now does to the expense of petroleum production, relieving to that extent the cost distributed among the products universally used in bulk such as gasoline. It would seem that a farsighted economic policy, properly directed, might eventually contribute to a lowering cost for motor fuel, just as a proper shaping of coal economics could be made to relieve the focus of expense now exclusively borne by fuel coal[3]—the two conspiring to lower the cost of living.

THE WAR SITUATION.

The latent weakness of the petroleum resource has become apparent under the influence of war stress. By encouraging the petroleum demand without being able to stimulate the supply in like degree, the war has merely brought into the immediate present an issue under way and scheduled to arrive in the course of a few years. The war, therefore, permits us to observe the weak points in the resource development as experienced facts, instead of in the light of logical deductions even one stage removed from observations. In short, the war brings the petroleum issue to a head, making the whole problem of the resource a problem of the present emergency also.

The importance of petroleum to modern warfare is obvious and needs no detail here. It is natural that the American resource is playing an important war-time rôle and in turn has been strongly influenced by the martial situation.[4]

The outbreak of the European war in 1914 found the petroleum industry of the United States suffering from a period of low prices and depression occasioned by a gross overproduction in the Mid-Continent field, due principally to the remarkable yield of the notorious and unexampled Cushing pool[1] in Oklahoma. The demoralization of the normal course of international commerce also added a destructive element to the marked abnormal conditions affecting the industry, but readjustments in foreign trade were quickly effected and the unfavorable consequences of external circumstances were not long continued or far-reaching. Toward the end of 1915, owing to the declining output of the Cushing pool, to the acquisition by a few strong companies of a vast accumulation of surplus petroleum in the Mid-Continent field, thus withdrawing it from the open market, and to the general increase in automobile consumption of petroleum products, a tension between supply and demand developed which set prices on a steady climb, renewed confidence in the situation, and started a phenomenal wave of wildcat exploration in search of new supplies. This impetus met with a quick and successful response in the way of output; so much so indeed that the latter part of 1916 saw a measure of overproduction, with consequent price depression; less marked, however, than the sustained period of 1914–15. This second slump was a passing incident, for the demand for petroleum was too insistent to be met with continued ease. The advent of 1917, then, saw prices and demand again on the upward grade and at a height overlooking the attainments of the past.

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[1] A good picture of the problems facing the petroleum industry is painted by Bacon and Hamor, The American Petroleum Industry, 1916, pp. 798–806.

[2] The principle of multiple production has tremendous significance for the future; it is more fully treated on pages 67–70 of this paper and in Bulletin 102, part 5, of this series.

[3] This matter, for coal, may be followed in greater detail in Bulletin 102, part 4, of this series.

[4] A good account of the war reactions of petroleum is given by John D. Northrop, Our mineral supplies: Petroleum, Bulletin 666–DD, U. S. Geological Survey, 1917.

With the entrance of the United States into the war in April, 1917, it became very evident that the petroleum fields of the country had an important, and at the same time, difficult rôle to play—important, because an enlarging demand was in prospect to maintain the industrial and military activities of the allied cause; difficult, because production, hampered by a growing complexity of circumstances and already shoved to an extreme of activity by favorable prices, presented no prospect of filling the total demand, with little chance of the margin being covered by a growth of imports from Mexico.

As a result the petroleum resource to-day faces a demand that it can not meet. This situation is depicted graphically in figure 10. It may there be seen that the relations of 1917 can not be sustained throughout 1918 without the arrival of critical conditions, and a continuation through 1919 is impossible. The United States is now (April, 1918) consuming and exporting more petroleum than she is producing from her own wells and receiving from Mexico. The discrepancy, which is growing from month to month, is covered by a draft upon the petroleum storage in this country, the amount on hand January 1, 1918, being about 153,000,000 barrels.[2] And while

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[1] This pool, from June, 1914, until April, 1915, when it attained a maximum production estimated at 300,000 barrels daily (over one-third of the output of the entire country), dominated the petroleum industry of the whole United States.

[2] It may be pointed out that this storage can not safely be reduced below a certain minimum figure, say 50,000,000 barrels, needed to fill the pipe lines and keep the whole industry in course of operation.

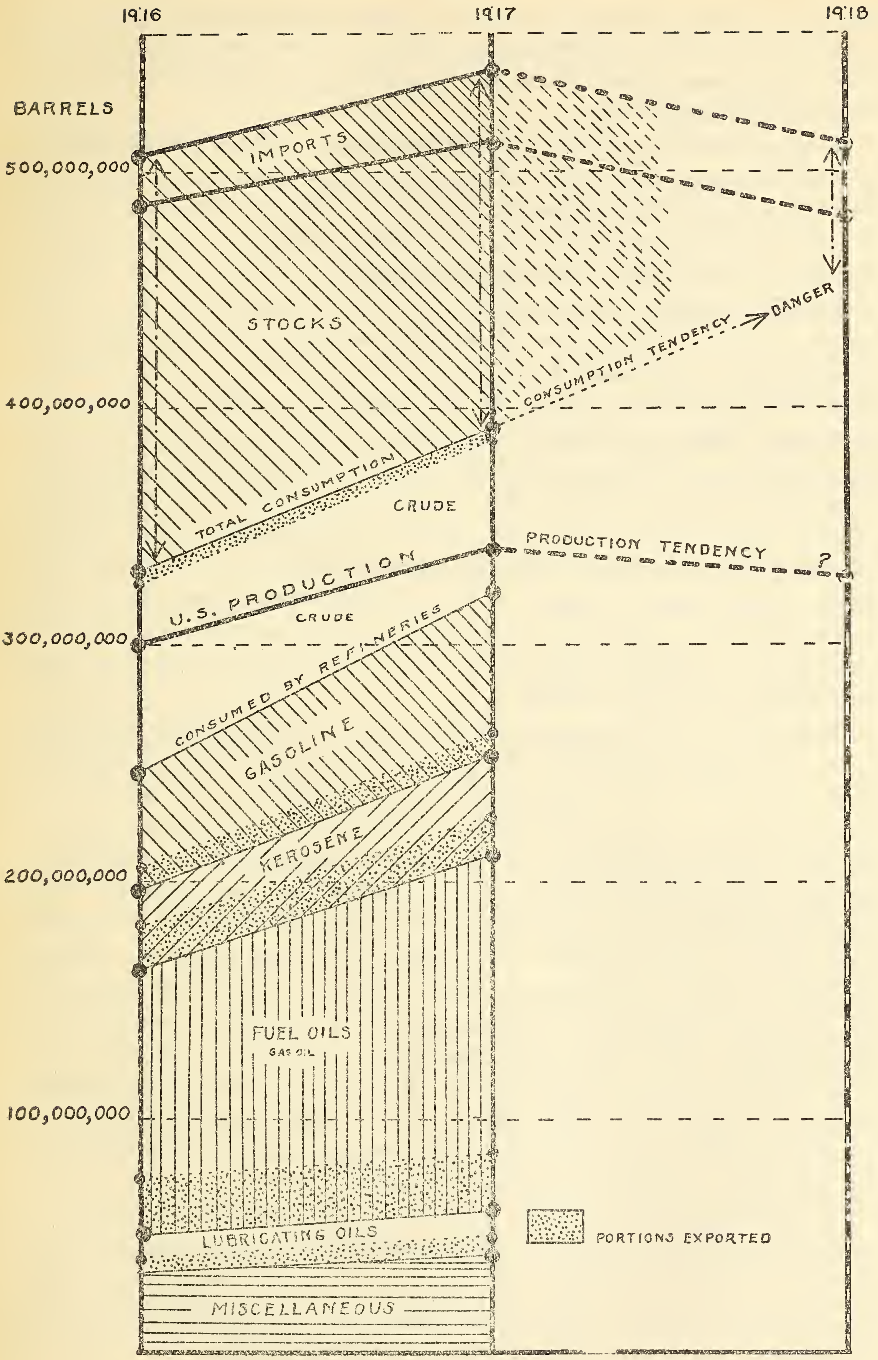

Fig. 10.—The current petroleum situation in the United States. Data from U. S. Bureau of Mines, U. S. Geological Survey, Bureau of Foreign and Domestic Commerce, and other sources.

the total demands for petroleum are increasing at a growing rate, the rate of production is slowing and there is scant hope of increasing the supply from Mexico.[1] In fine, the resource is not equal to all the demands looking to it.

We may examine in closer detail the trend of the growing demand for petroleum. As a result of the general speeding up of industrial activities, especially during the past year, there has not merely come an increased demand for all the petroleum products, but this demand has been preferential, focusing with particular intensity upon fuel oil. Especially has this tendency been marked in the eastern part of the country, the far West already having long been almost entirely dependent upon oil fuel. The growing use of fuel oil in the eastern part of the country is partly, if not primarily, a reflex from the coal shortage.[2] Many industries, finding coal difficult or impossible to obtain, have been turning to fuel oil, which for the time being has been "easier" than coal, due to the enterprise and superior distribution organization of the petroleum industry as compared with the coal industry, hampered by more critical limitations in transportation. Even to-day there is reason to believe that many enterprises under construction are planning on oil fuel in place of coal, while among established industries a shift from coal to oil has been going on to an extent not generally realized.

Thus coal is shifting part of its burden to petroleum and there is now a shortage of fuel oil, with good prospects of a critical dearth of this substance. While such matters are not open to accurate measure, it is roughly estimated that this shift has relieved upward of 10,000,000 tons of coal during the past eight months, much of that generosity being displayed in the very heart of the coal regions. That has happened even in Pittsburgh, the center of the most important coal district in the world. It is evident that such relief can only be temporary, and a continuation will soon lead, if it has not already, to more serious difficulities and eventually to a disastrous breakdown of fuel supply. It is absolutely essential to turn the tide back toward coal in the instances in question, with the possible exception of New England, where the change, due to peculiar transportation conditions, is valid. If coal can not meet the issue, then industrial activities must be curtailed. There is no other way out.[3]

As the demand for fuel oil has for some time been in advance of the demand for gasoline and other petroleum products, there has been no dearth of the latter, as they, or at least gasoline, must be turned out in quantity to support a growing production of fuel oil. This is why there has been no shortage of motor fuel at a time when there was a shortage of fuel oil. This also explains why it would be unwise to cut down in the use of unessential automobiles at the present time as a measure of petroleum conservation; that action would merely destroy a market for gasoline, which now supports the price-structure of petroleum, without being able to materially increase the bulk of the fuel oil turned out. With increasing stress, however, it may become necessary to pare down on gasoline consumption, but only as an accompaniment to a similar procedure for fuel oil.

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[1] If transportation from Mexico to this country can be facilitated by the construction of concrete tankers or otherwise, the situation may be considerably eased for the time being.

[2] It has been influenced also by increased naval and military needs.

[3] It is interesting that the most conspicuous maladjustment in the normal utilization of petroleum—the use of oil for steam raising—should have become the point of greatest weakness under war conditions. But such outcomes are inevitable.

The stimulation of domestic petroleum production to the utmost degree, the alleviation of labor difficulties and shortage of materials affecting oil-drilling, and the solving of shipping problems concerning coastwise and Mexico-to-United States movements of oil, are all matters of the greatest importance, which are receiving the active attention of the Government. It is not the function of this paper, which is concerned with a general economic study of the resource, to treat of these matters or presume even to suggest wherein the solution of the current problems lies. The war situation is here touched upon only in the belief that it illustrates unmistakably the unsoundness of the loose way in which the resource has been drawn upon, and points to the necessity for measures, not merely of alleviation, but of reconstruction in regard to the exploitation of the resource.

4. THE PROBLEM.

Sufficient, perhaps, has been set forth to indicate that the petroleum industry is not a separate activity to be dispensed with if necessity arises, but that its products are essential to the vital needs of the Nation. Indeed, it would scarcely be too much to say that the whole future of civilization depends upon a continued supply of motor fuel and lubricating oil, while the oil by-products potentiality holds out the prospect of presenting to the world, through the energies of this country, a gift even greater than kerosene has been. It would appear to follow, therefore, that these affairs should not be hampered or curtailed, if in any way the resource or its equivalent may be made to carry the responsibility well into the future. It is a matter of universal concern, then, to inquire if the impending exhaustion of the resource may be circumvented by modern scientific and technical knowledge; and if so, to ascertain the best procedure whereby this constructive force, as yet not fully used in this country, may be brought into effective action.

Granted that curtailment of activities fundamentally dependent upon petroleum is undesirable,[1] we may pass in review the means whereby the capacity of the resource may be enlarged so as to postpone or obviate the necessity for such curtailment. These means will be examined without special reference to their immediate availability under current economic practice, reserving for the next section consideration as to how the most important of them may be brought into effective play.

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[1] This does not apply unqualifiedly to fuel oil used for steam-raising purposes, as shown on page 33.

The enlargement of the resource capacity may be brought about in three ways: By prolonging the life of the unused portion of the domestic resource as it is now known; by developing low-grade domestic sources not yet drawn upon; and by building up the use of substitutes, particularly for gasoline, upon which a heavy and growing demand focusses.

PROLONGING THE LIFE OF THE PETROLEUM RESERVE.

The supply of petroleum unmined is so limited that the maximum should be obtained from it in order to prolong its availability. The enlargement of the reserve through the discovery of new oil fields, the elimination of wastes, and the extraction of a greater measure of service from the products represent the lines of progress in sight.[1]

Discovery of new oil fields.—While much of the oil-bearing territory of the United States is still undrilled, there is no hope that new fields, uncounted in our inventory, may be discovered of sufficient magnitude to modify seriously the estimates given. The reasonableness of this assumption will appear from considering the fact that between 1908 and 1916, during which time the most active exploration campaign in the history of oil development was carried on, the reserve was enlarged by only 1,200,000 barrels, a scant four years' supply at the present rate of consumption. This means that the petroleum resource of the country, like the coal resource, is now fairly accurately measured; and it would be vain to expect a significant increment from an unforeseen direction. Of course, new strikes and oil booms are to be expected, but these will lie for the most part within the area already represented in our measure of the petroleum reserve.

Elimination of wastes in production.—Far more may be accomplished in the way of enlarging the reserve by the elimination of unnecessary wastes in connection with production.[2] Under present practice, from 90 to 30 per cent of the oil is left underground.[1] Then, of the quantity produced, an appreciable percentage is lost by fire, and a significant portion dissipated by seepage and evaporation due to inadequate storage facilities.[2] On the average, therefore, it is safe to say that less than 25 per cent of the petroleum underground reaches the pipe line. If we subtract from this proportion the losses involved in improper and wasteful methods of utilization, the recovery factor becomes perhaps as low as 10 per cent.[3]

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[1] The bearing upon the matter of the oil fields of Mexico and Central America is discussed on pages 48–49.

[2] An effective and readable description of the physical wastes involved in oil production under present practice will be found in the Yearbook of the Bureau of Mines, 1916, by Van H. Manning, Washington, 1917, pp. 116–133. The technological investigations of the Bureau of Mines have been of the highest value to the industry in the way of supplying the technical means whereby these wastes may be combated. The ensuing paragraphs under this heading are largely a record of the accomplishments of the Bureau of Mines in this connection.

Knowledge of petroleum technology is far in advance of its application to oil production, due to the fact that this country is actively engaged in producing such knowledge, but has at the same time provided no adequate machinery for putting this knowledge into play, once it is produced.[4] Of course part of this advance gets into action where the gain from such application accrues to specific interests, but by and large there is a marked underconsumption of technological science, the discrepancy being often credited, though with questionable validity, against the difference between theory and practice. We may review some of this technological knowledge already in stock, having in mind that the supply is rapidly increasing.[5]

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[1] "Estimates of the total amount extracted range from 10 to 70 per cent, 90 to 30 per cent being left in the ground."—Van H. Manning, Yearbook of the Bureau of Mines, 1917, p. 127.

"It is universally acknowledged that by the usual production methods much oil is left underground, the general opinion being that at least 50 per cent of the oil in a field remains unrecovered when the field is abandoned as exhausted. From the writer's own investigations he believes the average recovery is even less * * * "—J. O. Lewis, Methods for increasing the recovery from oil sands, Bulletin 148, Bureau of Mines, 1917, p. 7.

[2] Evaporation robs petroleum of its lighter components (i. e., gasoline), hence the value loss is much greater than is apparent from the bulk removal.

[3] This is not to be taken as an exact figure, but merely as a rough expression of magnitude. No one, of course, can estimate such a matter closely. Twenty per cent would certainly be too high; 10 per cent, therefore, is not far from the true proportion and is a very salutary figure to accept.

"What effort have we made to conserve this supply and to utilize it to its greatest advantage? We have made little effort until very recently to do these things. We have been wasteful, careless, and recklessly ignorant. We have abandoned oil fields while a large part of the oil was still in the ground. We have allowed tremendous quantities of gas to waste in the air. We have let water into the oil sands, ruining areas that should have produced hundreds of thousands of barrels of oil. We lacked the knowledge to properly produce one needed product without overproducing products for which we have little need. We have used the most valuable parts of the oil for purposes to which the cheapest should have been devoted. For many years the gasoline fractions were practically a waste product during our quest for kerosene; with the development of the internal-combustion engine the kerosene is now almost a waste product in our strenuous efforts to increase the yield of lighter distillates." (Yearbook of the Bureau of Mines, 1916, Washington, 1917, p. 117.) If we add to this quotation the statement that gasoline is now almost a waste product in our efforts to make fuel oil help out a bad coal situation, the picture will be true down to April, 1918.

[4] An analogous situation would obtain if laws were made with no provision for putting them into execution.

[5] The treatment here, of necessity, merely touches on the more significant features. For details the reader is referred to the numerous publications of the United States Bureau of Mines concerning this matter.

The two greatest wastes connected with oil-well drilling are caused by the harmful infiltration of water from water-bearing strata and the uncontrolled escape of natural gas encountered in the course of drilling. Water is a formidable enemy to oil extraction; as the position of the oil depends, in part, upon a nice equilibrium between oil and water, the undue influx of water into the drill hole means a reduced recovery of oil, if not a total loss of the well; and not only may a single well be completely ruined by inadequate protection against water, but what is more grave a whole field of operations may thereby be spoiled. The damage done in the past by water is immeasurable and largely irretrievable, but the danger from water may be controlled by means of a method of cementation already employed with success in California and Texas, whereby a water-tight band of cement is forced into the space between the well casing and the water-bearing stratum.

Many wells in sinking penetrate gas-bearing formations, and in such instances it has usually been customary to suspend operations while the gas escaped into the air, so that the pressure might be relieved against which continued drilling was difficult or impossible. The actual waste of gas due to this circumstance has been first and last enormous, amounting to billions, if not trillions, of cubic feet, with a fuel equivalent of millions of tons of coal; indeed, it would be safe to say that over half of the natural gas developed to date has been made no use of whatever.[1] But this physical waste, great as it has been, is of small consequence as compared with the waste of the energy represented by the gas-pressure, the dissipation of which leads to a reduced and more difficult recovery of the oil. The gas, therefore, is not only substance but energy, and represents a force which must be conserved for the sake of later gaining a proper petroleum yield. It is rather interesting that the waste of oil and gas involved in the premature production of gas may be prevented by comparatively simple means; namely, by drilling in a medium of mud-laden fluid which serves to encrust the critical parts of the drill-hole, sealing off the formations so that there is no improper escape of gas and preserving the conduit intact down to the productive stratum.[2]

After the oil is struck, there are many methods for controlling the output so as to avoid the waste incidental to much of the current practice. The flow may be controlled by rather elaborate mechanical devices, preventing an overproduction;[1] gushers "gone wild" may be capped and brought under subjugation; "blow-outs" may be guarded against and prevented; and losses due to fire, seepage, and evaporation largely nullified through adequate development of storage facilities. All these gains will accrue more fully through widespread application of well-known engineering technique already successfully practiced in many instances.

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[1] See R. S. Blatchley, Waste of Oil and Gas in the Mid-Continent Fields: Technical Paper 45, Bureau of Mines, 1913.

J. O. Lewis and W. F. McMurray, The Use of Mud-Laden Fluid in Oil and Gas Wells: Bulletin 134, Bureau of Mines, 1916.

[2] This process is described in detail in Bulletin 134, Bureau of Mines, 1916. There are numerous details of drilling practice which are subject to improvement, but these need not be gone into here.

The gas that almost invariably comes forth along with the oil customarily carries some of the lighter components of the oil itself. These components are recoverable by means of appropriate methods in the form of a very volatile gasoline, which can be blended with a heavier petroleum distillate to form commercial gasoline. Until a few years ago, the recovery of the gasoline suspended in natural gas was neglected, but now a very significant yield of this so-called "casing-head" gasoline is obtained.[2] The natural gas is made to yield up its gasoline either through compression, which squeezes out the liquid content, or by absorption, which entices it out by means of a certain type of oil which later is heated and thus forced to yield up in turn the gasoline absorbed.[3] Even with full gasoline extraction, however, there remains in many fields much more gas than can be consumed by legitimate demand, which necessitates a waste of the surplus, unless it can be cheaply transported to points where demand exists.[4] In this connection possibilities open up in connection with processes of liquefaction, by means of which the gas may be compressed into reasonable bounds for transportation.[5]

Due chiefly to the decline of pressure upon the escape of natural gas, wells quickly mature and then produce at a declining rate; but recent investigations go to show that even when a well is apparently exhausted, its full quota of oil has by no means been exacted. On the contrary, as demonstrated by established practice in Ohio and elsewhere, an additional yield may be forced by means of compressed air or its antithesis, a vacuum. The more promising of the two methods consists in forcing compressed air down to the porous oil-bearing formation, thus driving the oil to positions reached by pumping wells. The full possibilities of these methods may not be safely forecast, but they are certainly capable, if widely applied, of increasing by a large percentage the future yield of the country over the estimates made in respect to current practice.[1]

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[1] Thus, for example, the flow from Mexican oil wells is at present held down to the transportation capacities available for export, avoiding a tremendous local overproduction.

[2] Production of gasoline from natural gas has grown from 7,000,000 gallons in 1911 to 104,000,000 gallons in 1916.

[3] The absorption method is especially adapted to "dry" gas lean in gasoline vapor.

[4] When the natural pressure is insufficient or distances too great, the normal transportation through pipes is unprofitable.

[5] See I. C. Allen and G. A. Burrell, Liquefied products from natural gas: Technical Paper 10, Bureau of Mines, 1912.

It would seem, then, that the wastes in connection with oil production, which are exceedingly heavy, are more due to inadequate utilization of technical knowledge, than to lack of means for effecting the economy. To gain a greater return from the resource, then, is more a matter of shaping a proper economic situation in respect to its exploitation than it is a matter of technological research.

Greater extraction of values.—We have seen that the oil in sight in the United States can not be reasonably expected to undergo significant enlargement through new discoveries of oil-bearing territory. The main hope of prolonging the life of the resource, therefore, lies in the two-fold direction of applying improved production technique, as already noted, which will, let us say, double the resource, and of gaining a fuller measure of value from the oil extracted, which is capable of multiplying the resource again by another factor no less great. Improvements in value extraction from the petroleum output will come through the extension and further improvement of "cracking" methods of distillation; through improvements in the design and efficiency of the internal-combustion engine; through the widening use of the Diesel type of engine, thus gradually deflecting fuel oil from its illegitimate rôle of a steam-raising understudy to coal; and through a carefully planned program for building up a great oil by-products industry to give multiplications of value to the portion of oil left after the energy, light, and lubricating values are extracted.

The "cracking" method of petroleum distillation has already been adverted to as representing the most promising means in sight whereby the growing demand for gasoline can be met from a slowing production of crude petroleum. The principle, therefore, is of the utmost importance, since it can be made to shove into the future the most threatening limitation to the growth of the automotive activity. Many "cracking" processes have been developed, all giving the same result, namely, a larger yield of gasoline at the expense of heavier components; but two of them stand out with especial prominence. These are the Burton process, for many years in successful practice in the refineries of the Standard group; and the Rittman process, recently developed by the Bureau of Mines and now also established on a commercial basis.[2] There is no need here to go into the technical differences between these processes; the principle is the matter to which emphasis is called. "Cracking" is the leading potentiality in petroleum refining, no less so because it permits the production of the other main products according to demand, without sacrifice of by-product possibilities.[1] The importance of the whole matter may be evalued by having regard to the fact that at present, even with "cracking" well launched into practice, less than one-half of the petroleum produced is manufactured into products representing an ideal apportionment[2] of the raw material into its components.[3] The production of gasoline may be doubled eventually or even more greatly multiplied without increasing the production of crude petroleum.[4]

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[1] For example, the petroleum reserve is 7,000,000,000 barrels, with a valuation on the basis of 1915 prices of $4,500,000,000. For each 1 per cent gain in extraction there will accrue to the reserve 70,000,000 barrels, worth $45,000,000. Expressed in another way, a 60 per cent gain in extraction efficiency will yield the equivalent of the total oil production to date in this country.

[2] See Rittman, Dutton, and Dean, Manufacture of gasoline and benzine-toluene from petroleum and other hydrocarbons: Bulletin 114, Bureau of Mines, 1916. See also Yearbook of the Bureau of Mines, 1916, Washington, 1917, pp. 131–133.

The internal-combustion engine of the type currently in use in the United States has been the subject of greater refinements in special qualities—luxury qualities—than in respect to efficiency. That is evidenced in the widely varying gasoline consumption on the part of the familiar brands of automobile motors, which show a range from 20 miles and more to the gallon down to a yield of only 6 or 8 miles in the case of high-price cars. While the sacrifice of efficiency in favor of special qualities is, perhaps, legitimate to a certain degree, it would appear that the desire for invidious distinction has led to an undue focus of attention away from utility. With the rigors born of resource limitation—a certain eventuality—and upon the passing of the automobile more fully from the realm of a luxury into that of a necessity, a greater and more universal reach toward motor efficiency may confidently be counted on. But improvements in motor design will not lie along the single line of gaining more energy from gasoline; the effective use of heavier petroleum distillates, such as kerosene[5] and fuel oil, and of other liquid fuels, such as alcohol, benzol, and tar oil, will be planned for and the broad trend of motor development will shape toward the character of the resource in its entirety—a bent as yet only dawningly perceptible. Whether radical changes in motor principle are in prospect is a question that need not affect the present argument.

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[1] It should be clearly held in mind that "cracking," with its attendant by-product possibilities, is a matter in constant course of development. The Bureau of Mines is actively engaged in furthering research and experimentation along those lines, though progress is hampered by inadequate financial resources.

[2] An ideal apportionment can not be attained so long as there is an overproduction of crude petroleum in respect to the demand for gasoline and other motor fuel, kerosene, and lubricating oil, and there remains an economic demand for such an overproduction. Hence the extent to which "cracking" may be applied is, of course, limited by economic factors.

[3] "We are to-day efficiently—that is, for gasoline and lubricating purposes—not more than 30 per cent of our oils. The other 70 per cent is used in competition with coal or exported for foreign countries and is generally sold for less than cost of production." Yearbook of the Bureau of Mines, 1916, Washington, 1917, p. 133.

[4] "Cracking" brings in the asphaltic oils as effective producers of gasoline, a fact of no small economic significance.

[5] "Perhaps no phase of the fuel situation has so interested automotive engineers as the use of kerosene in place of gasoline. Present market conditions are such that kerosene is one of the cheaper petroleum products, and as it has already been demonstrated to work satisfactorily in internal-combustion engines under certain conditions, there has been a great desire to render it available for general use in automobiles. The Bureau of Mines has had called to its attention many devices for the utilization of kerosene, but believes that mechanical development in this particular line is a mistake. The logical and reasonable way to utilize kerosene is not as such, but as a mixture with

In point of bulk nearly three-fourths[1] of the petroleum consumed in the United States goes into the production of power. Of this amount, one-quarter[1] is employed in the form of gasoline as a motor fuel,[2] while three-quarters,[1] in the form of crude petroleum and fuel oil, is used as a convenient substitute for coal chiefly in firing steam boilers.[3] While the efficiency of the internal-combustion engine is much greater than the steam engine, now commonly referred to as "wasteful" in comparison with more modern types of power generation, the use of the superior principle has thus far been confined in this country almost exclusively to an explosion motor using gasoline—the ordinary automobile engine familiar to all. The fact has generally been ignored in this country that a type of engine, comparable in efficiency to the gasoline motor, but making use of heavy oils (as fuel oil and even crude petroleum) and suitable for power generation on a large as well as a small scale, has for many years been in successful use abroad. This is the so-called Diesel type of engine, which has its conception as far back as 1893 and "has proved to be, from a thermal standpoint, the most economical heat engine so far devised, and the one that most nearly approaches theoretical maximum efficiency."[4]

This high-compression oil engine, as it may be termed, gains its energy from the expansion that results when oil is sprayed into a cylinder filled with compressed air and ignites under the influence of the heat of compression. The relative efficiency of this type of engine may be shown in the accompanying tabular comparison:

The efficiency of the Diesel type of engine.[5]

	Efficiency.
Diesel type of oil engine	4
Oil-fired steam engine (triple expansion type)	1.6
Coal-fired steam engine[6]	1

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the gasoline produced with it in the refining of crude oil. In other words, attention should not be given to the utilization of kerosene, but to the utilization of petroleum distillates containing both the gasoline and kerosene fractions of crude oil."—E. W. Dean, Fuel for automotive apparatus, Journal of the Society of Automotive Engineers, January, 1918, p. 53.

[1] Rough approximation.

[2] It has been estimated for the United States that the horsepower of gasoline internal-combustion engines is over twice that of all engines driven by steam. While the latter are more continuously used, the importance of the gasoline engine in power generating is strikingly great.

[3] The relatively small quantity of kerosene used in power generation need not enter the present consideration. A small portion of fuel oil is used for gas making and for other purposes than steam raising, but for most of this work coal is likewise effective.

[4] O. P. Hood in Technical Paper 37, Bureau of Mines, 1913, p. 8.

[5] Figures generalized from data presented in Technical Paper 37, Bureau of Mines, 1913, pp. 12–15.

[6] For marine use the advantages of the Diesel engine over the coal-fired steam engine includes the factors of speedier bunkering, greater fuel storage, etc.

The Diesel type of engine, therefore, offers the means for greatly increasing the power-generating capacity of the petroleum yet to be produced in the United States, in itself alone having the ability to double the energy extraction from the 7,000,000,000 barrels of petroleum still under ground. But the true significance of the prospect does not appear from the general consideration. In connection with marine service has this principle its richest promise; the advantages of oil over coal for ocean shipping are well known and obvious. If America plans, as she must, on a great expansion in foreign trade and the building up of a substantial merchant marine, she would ignore her most potent point of superiority if she neglected the bearing of the Diesel engine on this matter.

It may be a source of surprise to some that the Diesel engine has been so largely neglected in this country. In this respect, a quotation from a report of the United States Bureau of Mines may be of interest.

> Diesel developed his engine in the early nineties, and has since then greatly improved it and has made of it a most succesful and efficient power producer. At present it is thoroughly dependable and will burn a great variety of oils * * *. Although the prime requisite in Europe seems to be economy in operation, low first cost seems to be a more important requirement in this country, and at first comparison with the steam engine the Diesel seems to be exceedingly costly. Small imperfections in mechanical construction, up to within a very recent date, seem also to have had their influence upon the non-construction of the engine in the United States. Also, although the general industrial profits within the United States are large, the very abundance of raw materials and the general extravagance in their use seem to have combined against the wide adoption of this engine, in spite of its being so highly efficient, and in spite of the fact that it has met with such success abroad. * * * The generally wasteful methods of steam raising in this country must give way to the more efficient methods of fuel utilization that now prevail in Europe, if the United States is to maintain its present position or compete with other countries in the manufacturing industries. With a more conservative use of the Nation's abundant fuel supplies and a better development of the by-product industries, there is no reason why the heavy-oil engine should not materially aid in the more efficient utilization of the fuel resources of the United States.[1]

The use of gas oil, a high-grade fuel oil, in the manufacture of city gas represents a practice largely unjustifiable on the basis of resource economy. In 1915, the amount used for this purpose was about 16,000,000 barrels,[2] or roughly 6 per cent of the domestic petroleum production. With the exception of about one-fifth of the amount, which was employed for making oil gas in the Southwest, where coal is lacking, the bulk of the gas oil was used for carbureting or enriching the luminosity and calorific power of the various types of city gas made from coal, in order to enable the product to meet standards imposed by municipalities—standards in part a hold over from the days when the flat-flame use of gas made luminosity a necessary feature.[1] While, broadly speaking, the use of oil in gas manufacturing is a degradation, the practice is not only economically justifiable but actually desirable so long as the main outlet for fuel oil is for firing steam boilers, a use still more degraded with the added disadvantage of offering a smaller inducement for refining.[2]

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[1] I. C. Allen, Heavy oil as fuel for internal-combustion engines: Technical Paper 37, Bureau of Mines, 1913, pp. 9–10.

[2] See C. E. Lesher, Artificial gas and by-products: Mineral Resources of the United States for 1915, United States Geological Survey, p. 1051.

In addition to the extension of "cracking" distillation, improvements in motor design, and widespread use of the Diesel type of motor to replace the oil-fired steam engine,[3] an unlimited field of advance in increased value extraction opens up in connection with the building up of an oil by-products industry. But this matter has been emphasized in the preceding pages[4] and need not be detailed again at this point. The greatness of the opportunity, however, should not be underestimated.

Development of foreign sources of supply.—In addition to the domestic production of petroleum, this country since 1911 has been drawing upon the oil fields of Mexico at an increasing rate, so that in 1917 that country supplied roughly one-tenth of our needs. The pools of Mexico, accessibly situated in the Gulf Coastal Plain, are the richest in the world and are capable of a much greater annual production than has yet been taken from them. In fact, the output is mainly under the control of British and American interests, and is held in check, especially at the present time. In the Central American region in general, there are other promising oil districts, though none is developed in any way comparable to the Mexican deposits. It is not unreasonable to expect that further exploration and development will make available a reserve of oil in Mexico and Central America equal to the total remaining in the United States.[5]

These deposits, accordingly, offer themselves in increasing measure to supplement a waning domestic output. Their aid should be accepted, but their availability is incidental upon many uncertain factors, and obviously it would be unwise to grow into dependence upon them or permit their presence to offset action regarding the efficient utilization of our own resource. At best, these deposits and especially those in Mexico, if fully available and barring international complications, would put off the period of petroleum exhaustion in the United States for only a matter of say a couple of decades; hence their presence does not change the urgency of the domestic issue. Moreover, the high-use employment of these deposits—the output is now used dominantly for fuel purposes—would be to the best interest of Great Britain, the United States, and other countries using the output, not to mention the advantage accruing to the producing Republics themselves. Indeed, it would seem, so far as such things may be determined from the outside, that Mexico would take the lead among the Republics concerned in developing a policy in regard to petroleum development that would prevent production from exceeding the demand for the high-use products, as this legitimate drain may be expected largely to exhaust the supplies within a generation or two.

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[1] See page 14, Bulletin 102, part 4, this series.

[2] An interesting war-time development in connection with gas oil has been the installation of toluol-recovery plants in large municipal gas plants for the recovery of toluol formed from the oil in the course of gas manufacture, thus adding to the supply of toluol contributed by the by-product coke oven. It is a striking coincidence that both coal and petroleum furnish the basis for the manufacture of one of the most effective explosives known.

[3] Coal and hydroelectricity should also assist in replacing the oil-fired steam engine.

[4] See pages 34–35.

[5] Little in the way of petroleum imports may be expected from other parts of the world; South American needs will probably more than absorb the future output of that continent.

On the whole, it would appear to be for the good of all concerned that the Mexican deposits should not be more wastefully exploited than those of the United States, for the world needs the full service of the aggregate supply.

DEVELOPMENT OF OIL SHALES.

Granted the utmost in the development and use of the remaining supply of petroleum, economic pressure from oil shortage will still be not far distant. Attention turns, therefore, to sources of supply other than the porous rocks of oil fields thus far exclusively exploited in this country. It is of great significance, therefore, that within the past five years geological explorations on the part of the United States Geological Survey have definitely established the existence of vast areas of black shale in Utah, Colorado, and Wyoming, much of it capable of yielding upon distillation[1] around 50 gallons of oil, 3,000 cubic feet of gas, and 17 pounds of ammonium sulphate[2]—the whole constituting an oil reserve aggregating many times the original supply of petroleum.[3]

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[1] Oil shale is not supposed to contain petroleum, but upon the application of heat, it is thought, organic compounds present react to form an oil resembling petroleum from which can be obtained essentially the same products that petroleum itself yields. But this matter needs further investigation, as it is by no means certain that some oil shales, at least, do not actually contain petroleum as such. In either event, however, shale oil is practically the equivalent of petroleum.

[2] The occurrence and distribution of these shales, together with the results of distillation tests, are given by Dean E. Winchester, Oil Shale in Northwestern Colorado and Adjacent Areas: Bulletin 641–F, United States Geological Survey, 1917, pp. 152–155. Yields up to 90 gallons of oil, 4,294 cubic feet of gas, and 34 pounds of ammonium sulphate were obtained from certain samples. The figures cited in the text, however, represent commercial averages typical of workable areas.

[3] It is estimated that the oil shales of Colorado alone underlie 1,400 square miles, with an average aggregate thickness of 53 feet, and are capable of yielding 20,000,000,000 barrels of oil, an amount approximately twice as great as the original petroleum reserve in this country, together with 300,000,000 tons of ammonium sulphate, valuable as a fertilizer, nearly 900 times the domestic consumption of that substance in 1915. The important rôle of ammonium sulphate in modern affairs is shown on the chart accompanying Bulletin 102, part 2, of this series.

While these shales have only recently come into notice a similar resource has for many years been profitably exploited in Scotland, New South Wales, and France, where nature has been less bountiful with petroleum; while in Germany the extraction of oil from low-grade coal and other bituminous materials has become a well established undertaking.[1] The financial success and national importance of the Scottish shale-oil industry is particularly significant, as this activity offers an established technology and a basis of experience for application to the domestic oil-shale matter.[2] A comparison of the domestic prospects with the foreign practice, in the way of yields and values, may not be out of place.

General comparison between oil shale of Scotland and of Colorado-Utah.[a]

Average yield from 1 ton oil shale.	Scotland.	Colorado-Utah.	Use.
Oil.......gallons..	24	50	Substitute for petroleum.
Ammonium sulphate.......pounds..	34	17–25	Fertilizer; nitrogen products.
Gas.......cubic feet..	2,000	3,000	Fuel.
Shale residue.......pounds..	1,600	1,500	Brickmaking; road making; possibly for extraction of potash. Undeveloped possibilities.
	1910	1918	
Cost of production.......	$2.00	$2.50–$3.50 (?)	
Value of products.......	2.80	3.25– 3.75 (?)	
Profit, per ton of shale.......	.80	.75– .25 (?)	

[a] Data generalized from various sources, including Bulletin 641–F, United States Geological Survey, 1917; Bacon and Hamor, The American Petroleum Industry, 1916; Hearings on oil shales before the House Committee on the Public Lands Feb. 26, 1918; personal communications from David T. Day and Russell D. George. The figures for Colorado-Utah are provisional rather than final, but are believed to be conservative.

It is apparent from this table and from the general situation in respect to petroleum that domestic oil shale may soon come into commercial importance as a producing source of oil.[3] Just when will depend upon the trend of the economic situation as affecting the production of petroleum.

As a matter of fact, considerable commercial activity has already commenced looking toward the exploitation of the richer shale areas, especially in the Grand River Valley region of Colorado and near by

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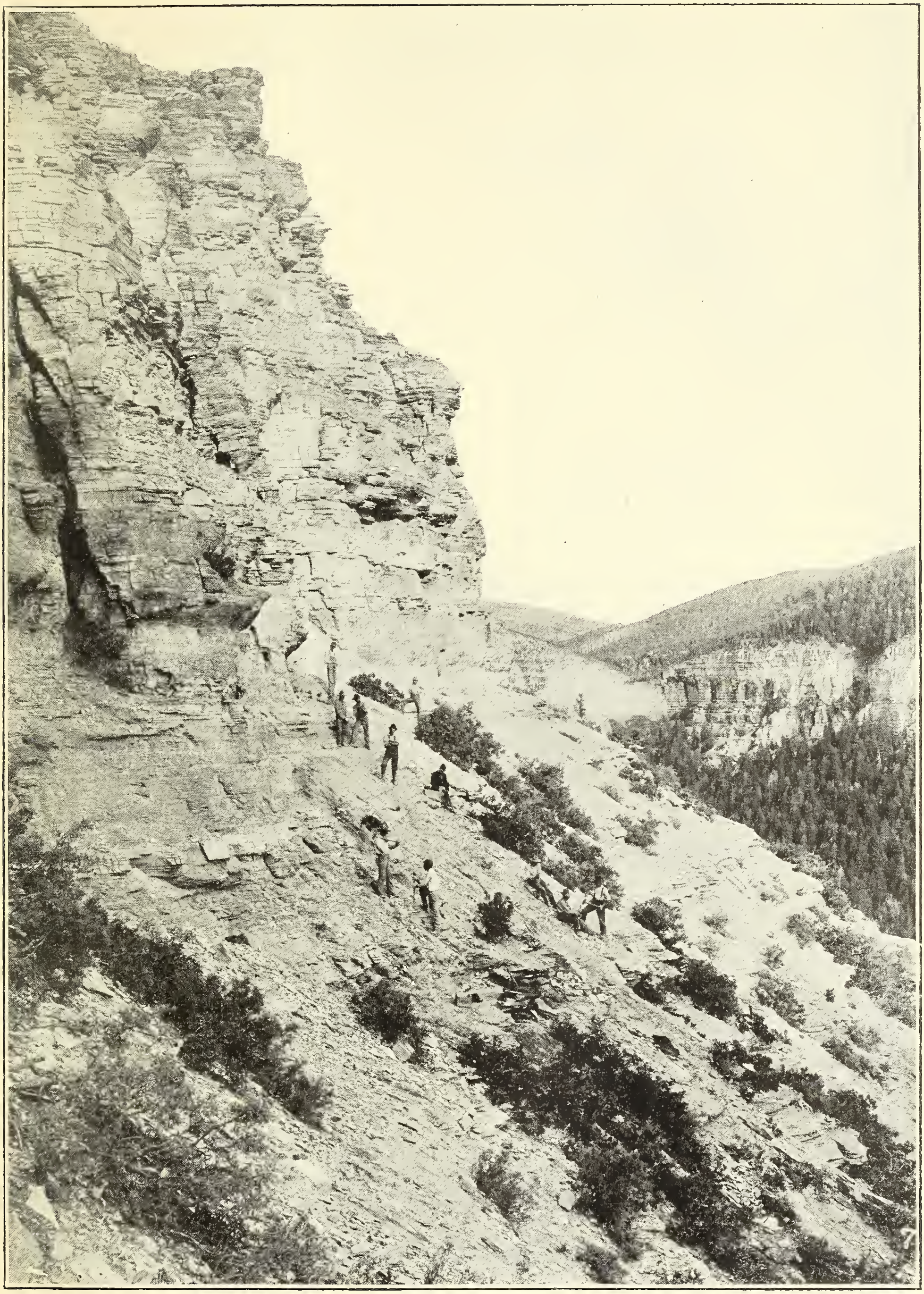
[1] The shale oil of Scotland has been of great service to the English Navy in the present war by supplying many oil-bearing ships with fuel, to the relief of trans-Atlantic shipments; while the German oil has proved invaluable to that country in supplementing an inadequate command of petroleum resources.

[2] A good description of the Scottish shale-oil industry, with many references to the literature, may be found in Bacon and Hamor, The American petroleum industry, 1916, pp. 807–844.

[3] "These shale areas will be developed in time on as safe and sane a basis as our coal mines of to-day. When that time arrives, the remains of oil prospecting will have fled and the whole complexion of oil producing will change. It will, literally, be oil mining with steam shovels in open pits and glory holes; and, later, tunnels and adits. There will be no lack of oil products for several generations to come, but the true oil fields of to-day will probably disappear within another generation and be replaced by oil mines." Dorsey Hager, The search for new oil fields in the United States: Engineering and Mining Journal, Jan. 5, 1918, pp. 11–12.



THE SUCCESSOR TO PETROLEUM. CLIFFS OF OIL SHALE NEAR GRAND VALLEY COLORADO.

Photograph by courtesy of Denver & Rio Grande Railroad.

in Utah. Numerous companies have been incorporated and some preliminary plants have started building. The whole matter, however, has been retarded by the uncertain status of the land laws, as well as by a general feeling of uneasiness as to the attitude of the current public-land policy toward any but a meager-scale type of development.[1] It is evident, however, on the basis of geological occurrence and experience abroad that a shale-oil industry can come into effective action only as a large-scale engineering procedure, accumulating its profit from a narrow margin made significant by the magnitude of operations.[2] The production of oil from shale, involving ordinary mining operations and a large distillation plant, partakes not at all of the nature of small-unit "wildcat" drilling by means of which the petroleum fields are developed.

We may pause for a moment, by way of parenthesis, to contemplate an eventual prospect of a great oil industry in the Rocky Mountains, producing two, if not more, of the four products upon which the food supply of the future turns.[3] And if we recall that northwest of the shale areas lie the richest beds of phosphate rock in the world, with water power and the acid fumes of great smelters as forces of extraction, it may not be altogether unreasonable to foresee a development of a food-production industry occupying the great plains that stretch eastward from the Rocky Mountains and energized by the application of mechanical tillage and chemical fertilization upon a scale for which the past presents no parallel.[4] Lest such a picture be regarded as too fanciful, it may be recalled that the United States Geological Survey has recently announced the discovery in Montana of phosphatic oil shales carrying a phosphoric acid content up to 15 per cent, thus combining in a single resource three of the four food essentials, gasoline, nitrogen, and phosphorus, lacking only potassium[5]—

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[1] These are direct reasons, but more fundamental inhibiting factors are inherent in the economic situation as explained on page 71.

[2] The Scottish shale-oil industry became successful only after it boiled down to a few large, efficient companies. The budding industry in Colorado would have the advantage, if not arbitrarily hampered, of skipping this inefficient stage and at the same time of taking over a developed technology shorn of its obsolescent features. It is estimated that a plant in Colorado capable of handling 1,000 tons of shale and clay would cost between $2,000,000 and $3,000,000, but a unit of this size would be small as such things go.

[3] Reference is had, of course, to tractor fuel and nitrogen (ammonium sulphate), the other two being potassium and phosphorus.

[4] The only element definitely lacking is potassium, and the prospect of that essential is more promising in the general western region than elsewhere in the United States. In connection with ammonia recovery in the by-product coke oven, suggestive experiments have been carried on looking to the absorption of the ammonia by means of phosphoric acid instead of by the customary sulphuric acid; the bearing of such a process, if successful, upon the shale-oil matter is significant.

[5] C. F. Bowen, Phosphatic oil shales near Dell and Dillon, Beaverhead County, Mont.: Bulletin 661–I, United States Geological Survey, 1918. This work opens up promising possibilities in respect to the occurrence of phosphoric acid in some of the oil shales elsewhere in the Rocky Mountain region, and suggests also a new field for petroleum exploration in those places where such shales occur under geological conditions which may have given rise to a natural process of distillation.

and even potassium is reported to be present in small amount in the Colorado shale.

While the most conspicuous oil-shale areas recorded in this country are in Colorado, Utah, and Wyoming, with the most immediate interest centering around those of Colorado and Utah, other oil shales are found in Nevada,[1] California, Montana, Arizona, Oregon and in many of the central and eastern States—aggregating an immense area and representing a potential source of oil sufficient to supply this country hundreds of years.[2] Of course it is evident that much of this shale has a prospective interest merely;[3] but there are certain beds overlying shallow coal seams, which offer themselves as productive possibilities even under present conditions, as the shale is a waste product to be removed anyhow in connection with the open-cut mining methods coming into vogue for close-to-the-surface coal seams. Thus, it is not impossible that coal-mining in the central and eastern part of the country, within a very few years, may support a budding shale-oil production, coming in, along with the output of the western shale-oil industry, to offset the decline in petroleum yield.[4] Still other possibilities open up in connection with the production of oil, gas, and by-products from cannel coals;[5] the whole matter in this wise passing over into the realm of by-product coal utilization, whose possibilities have been developed in an earlier paper of this series.[6] It becomes apparent, then, that coal and oil are not merely rivals, but are brothers in a common purpose—the production of energy and chemical products.

The presence in this country of extensive deposits of oil shale removes the danger of early physical exhaustion in respect to oil, but it does not necessarily insure a deferment of the period of economic exhaustion which is being prematurely rushed into the present by the current wasteful use of the limited petroleum resource. For that purpose an effective and adequate development of oil shale must start somewhat in advance of the wave of need that would normally dictate the launching of this leaner resource. That wave is already definitely in sight; the question is merely whether we will wait until it breaks or now prepare for the force of the impact so as to ease it off. It need scarcely be emphasized that any action directed toward the tying up of the oil-shale reserves, pending a determination of policy regarding their disposition, would be disastrous. The American public is probably sufficiently aware of the irretrievable harm wrought by this course of action in regard to certain other less vital resources, under the influence of the wave of so-called conservation that swept over the country a decade ago, to countenance a repetition of such temporizing action.

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[1] Experimental plants are being erected in both California and Nevada.

[2] The eastern shale areas are described by George H. Ashley (Oil resources of black shales of the eastern United States: Bulletin 641–L, United States Geological Survey, 1917), who provisionally estimates that southwest Indiana alone is underlain by shale sufficient to produce 100,000,000,000 barrels of oil, over fourteen times the present petroleum reserve.

[3] Ashley estimates that under present conditions a barrel of crude oil produced from eastern shale of average quality will cost about $4.20, little more than such an oil would be worth at present, barring by-product possibilities not possessed by its rival, petroleum.

[4] This whole matter of by-product development is of profound significance to the future of the Nation, to a degree, indeed, difficult of appreciation by anyone who has not focussed on the germs contained in the prospect. The possibilities of a shale-oil industry enmeshed with coal production affords promise to the already overdue arrival of a significant output of coal-pyrite, a product wasted in coal production, but needed for the manufacture of sulphuric acid. (See J. E. Pogue, Recovery of sulphur in Illinois coals: Met. and Chem. Eng., November, 1917, pp. 584–585.) That sulphuric acid is needed both in the recovery of ammonia from oil shale and in the refining of the shale oil itself is merely one example of how thoroughly by-product activities dovetail.

[5] See George H. Ashley, Cannel coals of the United States, Bulletin 659, United States Geological Survey, 1918.

[6] Bulletin 102, part 4, Coal: The resource and its full utilization.

DEVELOPMENT OF SUBSTITUTES.

Even with the most efficient use of the remaining supply of petroleum, and an appropriate development of shale oil in prospect, the petroleum situation can be additionally improved by a progressive utilization of substitutes for gasoline and fuel oil, so as to give better economic balance by relieving the products upon which fall the heaviest demands. Two substances, benzol and alcohol, are suitable for helping gasoline, and offer the advantage of a record of successful use in motor engines in Europe prior to the war, and of a marked extension of utilization there under the rigorous conditions of the present conflict, while coal and hydroelectricity may be brought to the aid of fuel oil.[1]

Benzol is a light liquid, somewhat similar to gasoline in character, obtained at present from the by-product coke oven. The production of benzol in the United States is at present small, owing to the fact that only about a twelfth of the bituminous coal mined is treated for the recovery of by-products. The full utilization of benzol therefore must go hand in hand with the development of methods, as outlined in a previous paper of this series,[2] whereby coal will be made to yield a complete measure of usefulness; indeed, the proper utilization of coal demands a market for benzol as a motor fuel, while the proper shaping of the petroleum resource permits and needs the coming in of benzol as an alternate for gasoline. Thus once more appears an example of how closely the various elements of the fuel situation are connected.

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[1] Recent work on castor oil production gives some indication that this organic product may come to be a significant source of motor fuel.

[2] Coal: The resource and its full utilization, Bulletin 102, part 4, this series. See especially pp. 10–13.

The total capacity toward benzol production possessed by the coal annually produced in the United States is upward of 1,000,000,000 gallons,[1] which in terms of gasoline represents about one-half of our annual consumption of the latter. Compared with gasoline, benzol yields better efficiency in the internal combustion engine, but presents a slight disadvantage in respect to use in cold weather. It may be used successfully in the ordinary gasoline motor by admitting a little more air than is customary for gasoline, or by mixing with gasoline.

Alcohol is familiar to everyone and as a fuel offers the advantage that it can be made from organic products which reproduce themselves from year to year and include vast quantities of materials that ordinarily go to waste.[2] Unlike the mineral fuels, therefore, it does not constitute a drain upon a reserve fixed in quantity. The difference in effectiveness for motor use between alcohol and gasoline is slight; for whereas gasoline yields a trifle more power to the gallon and is easier "starting from the cold," alcohol is safer, cleaner, and more pleasant as to exhaust odors. The capacity of this country in respect to alcohol production can not be closely stated, but if the output of alcoholic beverages is any criterion,[3] existing distilleries upon conversion could at once produce fuel alcohol to the extent of millions of gallons, whereas the substitution of waste products for grain would effect a great economy over the cost of denatured alcohol as made at present. If, in addition, the perplexing legal difficulties that now hedge in such a development could be circumvented, the use of individual manufactories on farms could readily furnish a perpetual supply of motor fuel at little cost, where a cheap motor fuel would have its most far-reaching social effect by tending to lower the cost of food.[4]

Artificial gas made from coal offers a convenient substitute for gasoline in certain types of stationary internal-combustion engines, while the suction producer plant, with its adaptability to the employment of lignite and other low-grade fuels, offers a wide field of usefulness to the partial relief of gasoline, especially in motor boats. Artificial gas may even become suitable for automobile use through the development of appropriate methods of compression or even liquification, so as to enable its storage in small compass. Even without such treatment, but under the stress of gasoline shortage, artificial gas has met with successful motor use in London during the present war; motor busses and other conveyance carrying large canvas containers filled with gas having now become commonplace objects in England.

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[1] On the basis of a yield of 2 gallons to the ton of coal.

[2] Alcohol can be made from starches, sugars, wood waste, sulphite liquors from paper manufacture, peat, cornstalks, etc. Its cost in Germany several years ago was as low as 25 cents a gallon; in England, 33 cents a gallon—prices comparing favorably with the present cost of gasoline in the United States. Rittman estimates on a prewar basis that alcohol would become a commercial fuel in the United States when gasoline exceeded 35 cents a gallon. (Journ. Ind. and Eng. Chem., May, 1917, pp. 528–530.)

[3] It is worthy of note that the consumption of alcoholic beverages and of gasoline during 1916 in the United States was approximately equal; each close to 2,000,000,000 gallons, equivalent to a per capita consumption of about 20 gallons.

[4] Tropical countries will find fuel alcohol very economical because of the practically unlimited supply of raw material available for its manufacture and the decided advantages of its use over gasoline in very hot climates. The Tropics, with their rank growth of vegetation, offer the most available energy source in sight, after coal, water power, and oil; and hence may eventually take on a much greater importance in this respect than they now possess in all other respects. Their capacity for producing fuel alcohol and food offer an interesting prospect to resource pessimists. The extraction of castor oil from the castor bean and stalk also presents a promising prospect, as several barrels of oil can be obtained per acre and the oil can be made into motor fuel and lubricants.

Fuel oil[1] has come into extensive use in the United States, especially in the far West, as a substitute for coal. It is more convenient than coal and is therefore adopted by industries wherever its price is low enough to permit its use. Its employment in this way can not be sustained, in view of the slowing rate of petroleum production and the counter demand that will come in increasing measure from the further development of "cracking" practice in refining and from the wider adoption of the Diesel type of internal combustion engine. It will soon be necessary, therefore, in any event, to bring coal and hydroelectric power to the aid of a growing number of those activities now dependent upon oil fuel; and the whole matter may be facilitated, to the benefit of the petroleum resource in particular, by constructive action in respect to coal and water-power,[2] so as to make their service in this respect more immediately available.

5. THE SOLUTION.

There are three outstanding features in the petroleum situation of unescapable significance. These are: the strictly limited size and decreasing availability of the petroleum reserve, the growing importance of certain of the products made from petroleum, and the tremendous waste involved in the current method of bringing petroleum into use.[3] The first two circumstances, of course, make the last important. If there were plenty of petroleum, waste in its use would not matter. Or if petroleum were of no great value, merely a luxury, neither waste nor limited quantity would make any great difference. Even if the supply were limited, but sufficient say for 50 years, it might be difficult to summon any interest at this busy moment to the issue. But petroleum is a basic necessity, as much so as wheat or wool, and its exhaustion is already beginning to be felt. The matter, then, can not be safely deferred.

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[1] Including crude petroleum.

[2] See Bulletin 102, parts 4 and 5, this series.

[3] It would be flattering to present usage to estimate that the resource is made to yield over 10 per cent of its latent value, considering the proportion left underground, lost in extraction, and inadequately used.

THE FUNDAMENTAL CAUSES OF WASTE.

If the petroleum supply is weakening, it is obviously desirable to examine the portion that is wasted. We have previously observed in some detail what these wastes are and where they take place—the oil left underground when the field is abandoned, the gas permitted to escape into the air or into barren formations, the destructive infiltration of water into the oil sands, the rapid production with demoralization of prices if the pool is large, the losses involved in storing the oil until it can be transported to market, the drilling of unnecessary wells, the inferior use to which much of the oil is put. These matters, of course, are well-known and notorious. But they are manifestations merely. We must look deeper for the root causes that give rise to these wastes.

In the production of other raw materials there are no such conspicuous wastes as characterize the production of petroleum.[1] There would appear to be, then, some fundamental factor peculiar to petroleum and conditioning the wasteful procedure common to its exploitation. This factor is not far to seek; it lies in the fact that petroleum is a migratory mineral[2] and moves underground in the direction of decreased pressure. This factor, activated by unrestricted competition in production as commonly practiced in the United States, is the fundamental cause of the wastes so preponderant with petroleum. Because petroleum is not fixed in position and much of the production, especially in young fields, is won through the efforts of small operators occupying small tracts, usually leased, there ensues a competitive scramble on the part of each operator to reach oil as quickly as possible and produce it as rapidly as possible. This means a ruthless sacrifice of all but the easy-to-get values. Even if an operator desires to defer production or restrain his output, as a rule he can not do so because a rival operator with a neighboring well will suck from under his feet the oil which his lack of action relinquishes. So long as the ownership of oil is determined by vertical boundaries, arbitrarily dividing a geologic unit or reservoir into many portions, just so long will there be hurried production with all its train of losses.[3] (See figs. 11 and 12.)

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[1] With which is included natural gas. The wastes in the production of coal are also conspicuous, but less than in the case of petroleum. It is a striking fact that the greatest wastefulness characterizes the exploitation of the energy resources.

[2] Natural gas and water also display this property; and in both there is waste. In the case of water, however, the waste is of slight consequence, since the supply is unlimited.

[3] Max W. Ball presents the matter very effectively in the following quotation (Adequate acreage and oil conservation, Proc. Amer. Min. Congr. November, 1916, pp. 322–333):

"There is the root of the whole trouble—the small holding. Let us go back over the history of the field.

"We saw that as soon as the field was discovered it was leased up in small tracts. Then we saw the Smiths, the Browns, the Joneses, and the Standard Oil drilling for dear life, each trying to get the oil from under his little tract and a bit of the other

The headlong production of oil is greatly facilitated by further circumstances. The gambling character of wildcat drilling in itself leads to the desire for quick returns, with little regard to the niceties of engineering efficiency. Then, the automatic character of production, once the oil is reached, attaches small cost to the actual production—not infrequently, in fact, it costs more to retard the output than to produce at maximum speed. Thus an incentive is lacking for exercising care with a product gained easily and ofttimes lavishly. There is, also, practically an unlimited demand for cheap petroleum for inferior uses, affording a convenient outlet for hasty production and tending to support the grossest overproduction with at least a modicum of profit.

Accordingly, because the cost of production is slight, wastes in production are of little consequence to the producer; while, due to the competitive race for extraction, production is unrestrained. Thus oil is produced with no adjustment to the legitimate (that is, high use) demand, which gives a surplus of cheap oil that takes advantage of and encourages the ever-present latent demand for oil fuel. Indeed, certain oil companies, usually small or newcomers in the oil business, find their only opportunity in the direction of encouraging the use of oil fuel; hence there is a strong pressure of advertising propaganda in this direction.[1]

This may appear to be an exaggerated account of petroleum production.[2] But such are the motives and conditions that prompt the production of the major part of the output of the United States and

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fellow's before the other fellow could get it. Why? Because each tract was so small it could be drained by wells on the surrounding tracts.

"We saw that the race was so keen that wells were improperly drilled, that gas was allowed to waste into the air or dissipate itself through barren formations, that water was allowed to enter the oil sands, and that great quantities of oil were left underground, never to be recovered. Why? Because the small holding forced each man to race with his neighbor.

"We saw the entire flush production of the field thrown on the market at once, demoralizing market prices, forcing the premature abandonment of wells in other fields, resulting in the burning of unrefined crude and the waste of the more valuable products. We saw the maximum production of the field go into storage, where the losses from evaporation and fire were enormous, and where the cost of the oil was nearly doubled. What caused these things? The fact that every holder of a small lease must drill it up as soon as possible.

"Lastly, we saw the cost of production more than 300 per cent what it should have been. And what was the reason? That every man must drill his lines as fast as might be, and must completely drill up his land at the earliest moment. Why? Because the oil under his small holding could be taken from him by wells on surrounding tracts.

"Ignorance there may be, carelessness there undoubtedly is, but back of ignorance, of carelessness, of reckless, headlong methods, is the real cause—the fact that the average holding is so small that speed is the owner's sole protection. Let him be careful if he can; let him be economical if he can find a way; but careful or careless, reckless or conservative, he must be speedy if he would survive. The small holding is his master."

[1] The fact that certain oils contain naturally a relatively small proportion of the higher-use products, such as gasoline, is beside the point. If the Appalachian field had yielded such an oil, methods of refining would have turned it into the higher channels of use. See the discussion on "cracking" distillation, page 18.

[2] Possibly because the picture is painted in terms of homely, everyday experience; but the issue is too important to be trusted to the cold atmosphere of technical expression.

hence dominate the situation. With increasing scope of organization in production, of course, these conditions tend to modify. With broadly integrated operations, production may escape entirely the influence of the factors noted. But, by and large, the situation in the United States is this: it costs a good deal to reach oil,[1] but little or nothing to produce it. When reached, the oil must be produced as rapidly as possible, else some one else will get it. There is an unlimited demand for the crude product, with profit in such sale. In brief, the free operation of the law of supply and demand under continuation of small-unit competition in oil production is forcing the sacrifice of the greater part of our most essential and most limited resource.

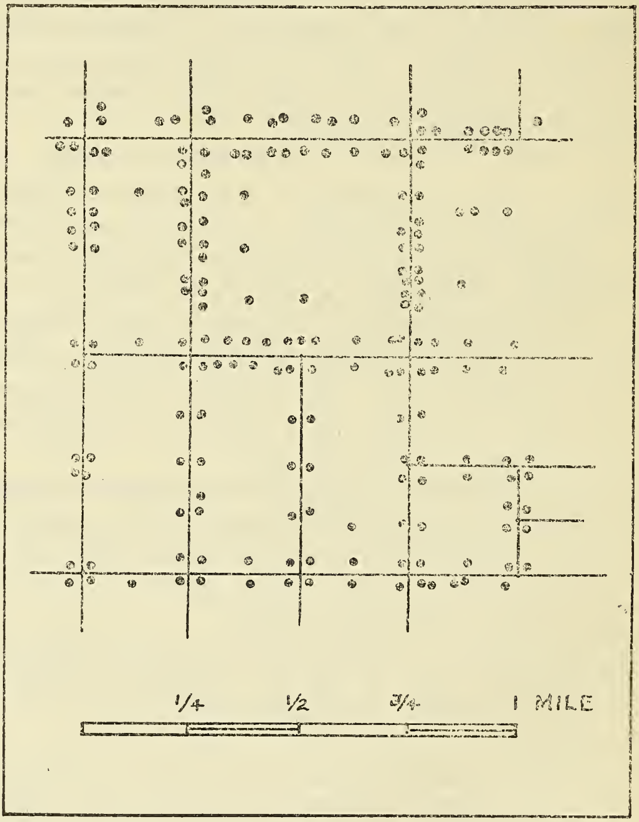

Fig. 11.—Diagram showing the relation of oil wells to property lines in a typical portion of the most productive light-oil field in the world. Note the small holdings, excessive number of wells, and the tendency of wells to occur in pairs on the opposite sides of property lines. This diagram epitomizes the fundamental cause of petroleum waste in the United States. Data from map by Carl H. Beal, Geologic Structure in the Cushing Oil and Gas Field, Oklahoma, Bulletin 658, U. S. Geological Survey, 1917, plate 4.

If so much be granted—and whatever the difference of opinion as to cause, the limited size and wasteful exploitation of the resource are incontestable—the question arises as to what may be done with the situation. Four lines of action, in the way of national policy, present themselves for consideration.

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[1] Much of this cost, under present conditions, is borne by unsuccessful prospectors.

THE LAISSEZ-FAIRE POLICY.

Industrial development in this country has been intrusted to the automatic control exerted by natural law—the law of supply and demand—working under free competition. Such interference with the natural course of industrial development as national policy has dictated has been in the direction of maintaining conditions of free competition against an integrative or monopolistic tendency. This policy of leaving industrial growth to the stimulus and retardation of attendant circumstances may be termed a policy of noninterference or laissez-faire. Such a policy apparently developed on the assumption that all industrial activities react alike and favorably to this treatment. If, however, at any later time it becomes clearly apparent that in a given field matters are working out disadvantageously under a sweeping-rule policy, it is a fit subject for inquiry whether a point of departure is not there afforded and justified in respect to a change in plan, so as to bring the activity into a more profitable and congenial atmosphere. It would appear that, so far as petroleum is concerned, a continuation of the policy of laissez-faire will perpetuate the circumstances which are forcing a premature exhaustion of a limited and vital resource.

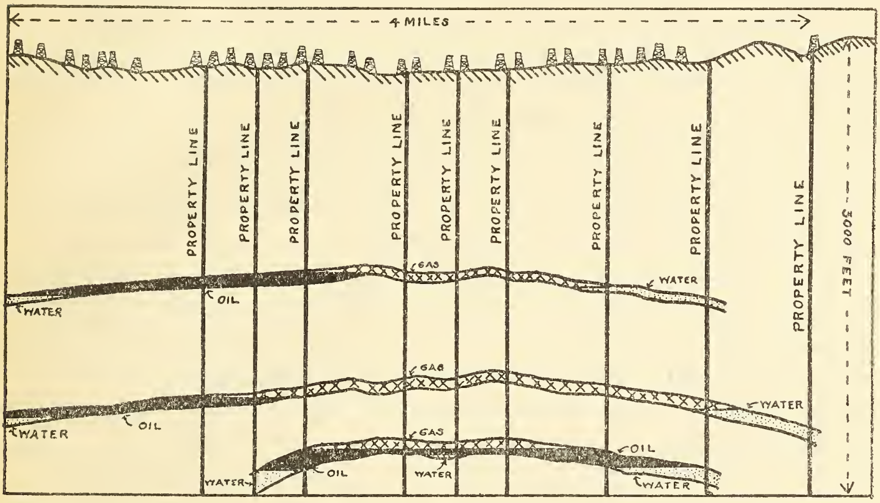

FIG. 12.—DIAGRAM SHOWING THE TYPICAL UNDERGROUND OCCURRENCE OF OIL, GAS, AND WATER, AND THE CUSTOMARY DISCORDANT RELATIONS BETWEEN PROPERTY LINES AND GEOLOGIC OCCURRENCE. THE MIGRATORY CHARACTER OF OIL RENDERS THIS TYPE OF DEVELOPMENT UNSOUND AS LEADING TO A RACING AND WASTEFUL EXTRACTION OF THE OIL. THIS DIAGRAM EXPRESSES THE UNDERGROUND RELATIONS OF THE SURFACE CONDITIONS DEPICTED BY FIG. 11. DATA FROM CARL H. BEAL, GEOLOGICAL STRUCTURE IN CUSHING OIL AND GAS FIELD, OKLAHOMA, BULLETIN 658, U. S. GEOLOGICAL SURVEY, 1917, FIGURE 3 AND PLATE 4.

The policy of laissez-faire is so firmly established and so apparently effective in the general run of industrial growth that many hesitate to abandon it in specific instances, however urgent the need in point. But at least the consequences of allegiance in such instances should be visualized. In the case of petroleum, under continued laissez-faire, we may expect to be confronted, some 15 or 20 years hence, with the discomforting realization that our domestic resource has been impoverished, a dependence upon a foreign country has developed, and the opportunity for betterment has passed—wasted. This is a simple matter of arithmetic, not an adventure in prophecy.[1]

THE ADVISORY POLICY.

In an earlier part of this paper, the recent developments in petroleum technology have been reviewed in a broad way, and it appeared that considerably more technological knowledge has been accumulating than has found a way into action. Much of this technical advance has been affected by researches and investigations in petroleum technology on the part of governmental bureaus, notably the Bureau of Mines[2] and the Geological Survey,[3] and in this way the Government has assumed an advisory capacity in respect to the development of the petroleum resource. Creditable progress in increasing resource efficiency has thus been attained—a heavy return, indeed, upon the small investment made in this direction.

Such work, advisory to industry, is of great importance and should be encouraged by adequate support.[4] But with petroleum, at least, technological advice and information alone are impotent to get at the roots of the trouble. So long as economic conditions encourage waste in petroleum exploitation, no amount of technical and scientific knowledge will more than scratch the surface of the matter. The advisory policy, therefore, is an incomplete policy—good so far as it goes, but it doesn't go far enough.[1]

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[1] Writes M. L. Requa, in speaking of the wasteful use of coal and oil:

"Our very prosperity makes us careless of the future; we feast and revel while the handwriting blazes on the wall in letters of fire, and we do not pay it even the cold compliment of a passing glance. As a Nation, we are wasteful, apathetic, and forgetful. We waste our natural resources with shameful prodigality; we are apathetic of the future, and we forget that our reserves of natural wealth are by no means inexhaustible. * * * We vaguely realize, if we condescend to think about it at all, that when such a time shall have arrived, in some distant generation, that centers of manufacturing must change and things generally undergo a radical realignment. And then we remember that the problem is, after all, one for distant posterity, and that posterity should shift for itself and we drowsily mutter 'laissez-faire' and forget the future in our supreme self-satisfaction in the present. * * * Those of us who believe that posterity must settle these problems of heat, light, and power are living in a fool's paradise, and must inevitably awaken within the next few years to face, subdued and chastened, the real truth." (Exhaustion of the petroleum resources of the United States, Senate Document No. 363, 64th Congress, 1st session, 1916.) The speed with which this prediction has come true has perhaps amazed even its sponsor.

[2] The United States Bureau of Mines was not established until 1910, but since that time its Petroleum Division has notably advanced the field of petroleum technology, as may be readily gathered from a survey of the publications of this bureau.

[3] The United States Geological Survey has for several decades been engaged in the geological study of the oil fields of the country and publishes an annual statistical record of the domestic output of petroleum. The mapping of the underground structures, as embodied in numerous bulletins, has furnished a wealth of information of immediate practical value in connection with the development of new territory and the location of successful wells; while the inventory of the petroleum reserve made by the Survey represents an invaluable contribution to resource knowledge.

[4] The United States only devotes some three or four million dollars a year to investigational work bearing on the mineral industries in their entirety—a strikingly low figure, considering the magnitude of the field.

THE AUTOCRATIC POLICY.

Secretary of the Interior Lane, in his annual report for 1915, says in regard to petroleum: "An absolute government would prohibit a barrel of it being used for fuel before every drop of kerosene, gasoline, and other invaluable constituents have been taken from it."[2] An autocratic government by fiat could probably eliminate waste from petroleum exploitation by enforcing arbitrary laws to this end. But we do not have an autocratic government and, moreover, the type is in the course of passing into universal discredit. But even democratic governments sometimes deal with such problems in a harsh or rather arbitrary manner; in point of fact, it is a somewhat widespread feeling that wastes and economic maladjustments can be legislated out of existence by wisely drawn laws, even in a republic. Fiat methods, however, apart from being inconsistent with our professed principles of government so as not to merit wide approval, may also be seen, both in the light of past experience and of common sense, to offer a prospect only of harm. Thus, to give extreme suppositions, a law demanding increased recovery from wells would resut in a lowered production, with an industrial mix-up; a requirement that oil be no longer used for steam-raising would cause the Southwest to starve to death; a call for efficient drilling would throw chaos into oil production. The legitimate and illegitimate strands have become so closely interwoven that it is now impossible to improve the pattern by plucking out the economically inartistic threads.

THE CONSTRUCTIVE ECONOMIC POLICY.

This country has applied the laissez-faire and advisory[3] policies to petroleum without adequate betterment of the situation so far as wastes are concerned. It has even tried certain forms of legalistic or dictatorial force in the way of interjecting competition into phases of the matter already integrated[4] or by nature noncompetitive,[5] but with no beneficent effect upon the resource as a whole. Neither technology nor law can meet the issue unaided—and no one wants the autocratic method, good or bad. Is there no way, then, whereby this country can administer its petroleum resource without waste, yet with fairness to all interests? Must we admit that to gain a legitimate service from petroleum we must sacrifice nine-tenths of the resource? Such a necessity is scarcely conceivable, yet it seems to exist. Such a necessity, indeed, does exist, so long as the petroleum resource is left subject to the untrammeled operation of the law of supply and demand under conditions of unrestricted competition in production.

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[1] An advisory policy is really a part of a constructive economic policy.

[2] An absolute government, indeed, would presumably go further and require the fuel residuum to be used in the Diesel type of internal-combustion engine instead of under steam boilers.

[3] No intent to belittle the advisory policy is in mind, but that policy is limited in the good it can accomplish by circumstances over which it, per se, has no control.

[4] The operation of the Sherman antitrust laws in disintegrating the Standard Oil Co. into a number of subsidiary companies is an example.

[5] Illustrated in the case of the Walsh bill (S. 2812, 1918), opening public oil lands to development in 160-acre tracts. The United States, through the Geological Survey, has spent millions of dollars in learning and proving that oil does not occur in 160-acre tracts, yet it tries to force oil to so occur by fiat, or, at least, ignores legally the fact that oil is migratory.

The betterment of the petroleum situation, in the last analysis, depends upon the recognition of a principle and the incorporation of that principle in a broad national policy bearing on all industrial matters—a policy which we may term a constructive economic policy. The principle is this: That natural economic law is not invariably beneficial in its action, however advantageous in the majority of instances; that it requires surveillance and, in those cases where it fails, constructive help. This principle is perhaps most strikingly exemplified in petroleum, where the automatic control exerted by natural law has unmistakably demonstrated incompetence, but it is also true of a sufficient number of activities to have general significance. A constructive economic policy is desirable, then, not on the score of petroleum alone, but in behalf of the industrial development of the country at large. It would be scarcely possible to create machinery to handle the petroleum problem effectively as a single matter; petroleum is too closely enmeshed with the whole industrial life of the country thus to be singled out.[1]

The general need for a constructive economic policy can not be gone into in detail here. Its general desirability and scope will probably become clearer in the course of the ensuing discussion on its applicability to the petroleum problem. In this respect, a constructive economic policy would come into effective play by seeking out those aspects of the petroleum industry in which natural economic law, as it now operates, has not led to sound development; it would then study those maladjustments and smooth them out by appropriate measures so as to bring the entire resource activity into effective operation. Sufficient, perhaps, has already been set forth in this paper to make clear that the glaring flaws lie in the realm of production and arise from the fact that the supply, due to various factors, is out of adjustment with the demand. If these degrading factors are permanently set aside, then the whole matter may be intrusted again, and this time safely, to the automatic regulation of natural economic law.

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[1] The need for a constructive economic policy is especially apparent in the production and utilization of mineral raw materials. If the reader could view, in rapid succession, the curves showing the increasing consumption of the various mineral resources and at the same time realize that the reserves of these resources (of the richness now worked) are strictly limited, he would be strongly impressed with the fact that sooner or later the world must make full use of the raw materials which are now so incompletely utilized.

A widespread and general feeling in regard to such matters seems to be, so far as may be gathered from everyday experience, that a constructive policy in regard to resource efficiency would prove destructive from a human or personal standpoint, and therefore resource waste is justified on the basis of its moral safety. This view seems also to have gained ground from the more or less current feeling that the moral obliquity of Germany is in part a product of her industrial organization, which has naturally lent no popularity to the idea. But these considerations are believed to be beside the point; mineral resources (as apart from organic resources) are limited in quantity, are being used up with extraordinary rapidity, and the time will come for each limited resource when waste can no longer be tolerated. No matter the justification of compromise on other grounds, sheer physical necessity will dictate full utilization. That time is almost here for petroleum, just as it is temporarily here for wheat. Individualistic proclivities must give way before resource exhaustion. But, on the other hand, it may be questioned, purely on a moral basis, if wasteful utilization can be on as high a plane as full utilization.

Lest a constructive economic policy be regarded as an unduly radical step, involving elements of greater danger than of prospective advantage, we may examine more specifically what its course of action would involve.[1] The main lines of advance are clearly marked out. They indicate that a constructive economic policy would discourage unrestricted competition in production, provide for a tapering use of oil for steam-raising, insure the development of petroleum by-products, pave the way for the sound establishment of a shale-oil industry, and stimulate the production of benzol and alcohol as motor fuel.

Discouragement of unrestricted competition in production.—We have seen that the geological occurrence of oil leads to lavish production, a tendency that is given extravagant license by the small-unit competitive mining operations prevailing in this country. Hence there has long been an overproduction of oil in respect to the real needs of the country, with frequent spurts of gross overproduction. In these circumstances lie the major causes of waste and inferior utilization all along the line. By some means production must be brought under the control of legitimate demand. A constructive policy, recognizing this desirability, will encourage a type of development that will hold petroleum in the ground until it is actually needed for high uses.

The first step toward this end would logically be to disfavor small holdings. In the case of the public lands, this could be accomplished by appropriate legislation permitting the patent or lease of adequate acreage.[2]

In the case of private oil lands, either developed or in prospect, a constructive policy will favor and facilitate integration, at least up to the point where each geological unit is occupied by a single producing activity. Anything short of this leads to competitive racing for extraction, the most potent single impetus toward wastefulness. As integration is a natural tendency, perhaps no artificial stimulus would be necessary to attain an appropriate result, other than a policy advertising its desirability and perhaps obtaining the passage of standardized leasing laws forbidding grants of inadequate holdings. Petroleum mining can not be administered so as to give every comer a chance; that is inconsistent with the public interest because of the peculiar occurrence of petroleum; so much of individual right must succumb to the common good.[1]

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[1] Any action that harms either established industry or the public interest is not constructive. Such may be the criterion through the use of which a constructive economic policy may safely be applied.

[2] Bills now pending in Congress (H. R. 3232 and S. 2812) scarcely go far enough in this direction.

Whether production should become integrated in further degree, or come more fully under the ownership control of the handling activities, transportation and refining, need not be settled here. Certainly, however, for good effect production must be controlled by demand working through refineries; production, then, can not be independent in fact. Hence integration in this respect is unavoidably present, whether materialized in formal arrangements or not.

The common objection that an integrative tendency must be combated as leading to monopoly need not detain the argument. A constructive economic policy may be expected to find means whereby it can protect the public from the undue exercise of the power inherent in large integrated activities. Indeed, that safeguard has already of late developed to considerable measure through the simple expedient of publicity of operations. Neither constructive policy nor integrated industrial operations will soon again underestimate the power of enlightened public opinion.[2]

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[1] The bearing of this matter on the public lands, although it is equally applicable to developments in general, is well expressed by Max W. Ball in testimony on the public lands given before the House committee on Feb. 8, 1918, as follows:

"It seems to me * * * that there are two fundamental theories as to the disposition of public lands * * *. The first of these is to so dispose of the public lands that the largest number of individuals will be able to make a living from them, make a profit from them, or in some way enjoy individually the benefits of the public domain * * *. Suppose we call that the 'individual-bounty' theory, which, I think, describes it fairly well * * *. The other theory is to so dispose of the public lands that their products will be available to the public with the minimum of waste and at minimum cost. Suppose we call that the 'consuming-public' theory, for want of a better name. Possibly as good an example as we have of that theory is the mineral-land laws, under which we have had such marvelous mineral development in this country in the last two or three generations. Those laws, you will remember, although they provide a limited area for each claim, make no restrictions as to the number of claims that may be operated together and therefore permit small unit operations or large unit operations as may be necessary to get the mineral products to the public at the lowest cost * * *."

[2] It may be presumed that the large units engaged in the handling of petroleum would have gone more fully into organized productions had not they faced a public opinion suspicious of any such trend toward what would popularly be termed "monopoly." As these activities could command, anyhow, all the oil they wished without directly controlling production, there was no pressing incentive to go into any branch of the activity that might invite further destructive attention from public opinion. Both the public and the petroleum industry have been the losers in this period, now passing, of mutual distrust.

The elimination of excessive competition in oil production, that is to say, of competition within the geological unit or reservoir, will go far toward placing petroleum on the same footing with other mineral products. It will lessen the gambling aspect of oil-field exploration by bringing a greater measure of engineering practice to bear on the search for oil.[1] It will strike to the roots of wasteful production and overproduction by enabling the producer to gain greater profit in holding the oil underground until needed and then producing it according to the best current technique than by rushing headlong into hasty production as is necessary under present circumstances. It will create conditions of supply that will cater indifferently to inferior uses, to the sustained benefit of all activities actually dependent upon the distinctive character of petroleum products. In a word, this simple expedient will prevent the migratory character of petroleum from working at severe cross-purposes, as it now does, with the best interests of the petroleum industry and the public.

Tapering use of oil as steam-raising fuel.—While better rounded integration in the production of petroleum will find physical wastes unprofitable and lose interest in supplying low-use demands, a constructive economic policy will also clear the path of certain obstacles now retarding an efficient utilization of petroleum. These obstacles are chiefly two: The large amount of fuel oil thrown on the market as a necessary product of refining, which must find an outlet; and the industrial dependency upon oil-developed steam power, strongly marked in certain parts of the country lacking in coal. A wise policy will turn the use of fuel oil into higher channels and narrow the necessity for employing the oil-fired steam engine.

In respect to fuel oil, we have already seen that "cracking" distillation can turn it in part into gasoline, while without change fuel oil may be used efficiently in the Diesel type of engine. Here are the means, then, for escaping the steam-boiler use of oil. "Cracking" may be expected to come into practice as needed, but its progress would be facilitated by extended research on a commercial scale in keeping with the true importance of this matter.[2] The Diesel engine has been scarcely used in the United States; its introduction on a broad scale may be facilitated by a campaign of educational information, by the encouragement of manufacturing plants, and particularly by favorable consideration for adoption in connection with the Navy and merchant marine of this country.[3]

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[1] A substantial gain from this will lie in the field of investments in respect to lowering the losses now so abundant in connection with fake and unsubstantial oil companies.

[2] Such work is being done by the Bureau of Mines, but with financial support scarcely in keeping with the potential importance of the experiments.

[3] The British ministry of reconstruction has a provisional committee for the internal-combustion engine industry which, presumably, will press this matter for Great Britain.

The disuse of the oil-fired steam engine may be encouraged and permitted through the proper development of other energy resources, such as coal and water power, as suggested in the two preceding papers of this series.[1] The extent of the dependency of the country upon oil-fired steam power is amazing in view of the slimness of the resource; changes in this respect, in any event, must be forced within a very few years. The lack of a constructive economic policy has permitted this country to run into its present unsound condition in respect to fuel oil; the sooner the enlarging use be turned into a narrowing use, the better.[2]

The fuel-oil problem carries peculiar significance to the Southwest, for most of the far western railroads and industries and much of the Pacific coast shipping are utterly dependent upon fuel oil for energy. Indeed, the fuel situation in the Western States and on the Pacific is fundamentally different from that in other parts of the United States. Because of the prolific oil fields of California, which came into play at the beginning of an era of great industrial growth and the distance of the Pacific region from important coal fields, petroleum in that section is both coal and oil, so to speak. It can not long play the double rôle; in fact, even now, the situation is badly strained. Accordingly, the matter there is already an issue of grave importance. The far West must either turn to coal, hauling much of it long distances, or else develop cheap electric energy from the streams of the Sierra and Coast ranges. It so happens, however, that over one-third of the available water power of the country is to be found in the States of California, Oregon, and Washington, ready to release oil from its crudest use as soon as an adequate policy of national water-power administration comes into play.[3]

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[1] Parts 4 and 5, this bulletin.

[2] The reduced utilization of fuel oil that would come from the wider employment of the Diesel type of engine and the substitution of coal and hydroelectric power in appropriate degree would practically eliminate the low-use demand for petroleum products, permitting the production capacity of the country to meet the legitimate demand for some years to come.

[3] The California State Council of Defense (Report of the committee on petroleum, July 7, 1917, p. 158) estimates that fuel oil in San Francisco would have to advance from $1.45 a barrel, the 1917 cost, to $2.66 a barrel—that is to say, double—before it would become as costly as coal at $8 a ton. "It is evident," this report goes on to say, "that at present relative prices of fuel oil and coal in California, few consumers of fuel oil will voluntarily give up its use and revert to coal * * *." This report also reviews the water-power situation (pp. 169–172) and states that the minimum potential water-power resources of California, Oregon, Washington, Nevada, and Arizona is 12,619,000 horsepower, 45 per cent of the water-power resources of the entire country. Of these potential resources only about one-tenth is now developed, the equivalent in fuel oil of 19,000,000 barrels annually, while approximately one-third "can be developed as required at an average investment cost which will permit of successful and profitable operation under present conditions of the western power market." The undeveloped but practicable water-power resources of this section, then, are capable of replacing over 50,000,000 barrels of fuel oil annually, or approximately two-thirds of the present consumption of fuel oil in this section. Hydroelectricity, the Diesel engine, and a slight use of coal are capable, if properly directed, of solving the fuel problem of the far West.

Encouragement of multiple-product[1] *(by-product) development.*—Even with better-rounded integration in production under way and the rôle of steam-raising fuel oil shifted to a tapering use, additional gain will result from a constructive shaping of the demands for petroleum by-products so as to create a balanced outlet for the full values contained in the raw material. This accomplishment will depend upon a clear appreciation of the fundamental importance and tremendous significance of multiple production in general, together with a true perception of the peculiar nature of the problem that this matter presents. Since by-products represent a field of comparatively recent growth, very immature as yet, and since, moreover, the term tends to connote products of *incidental* importance, it may be well to visualize the rôle of by-products in industrial growth, so far as this may be done in a broad, general way.[2] In this preliminary measure of the field we will confine ourselves to those industries engaged in the breaking down of raw materials into products, as the by-product principles are most outstanding and conspicuous there, though they are less obviously applicable to a greater reach of industrial activities.

Industries, such as the mineral industries, engaged in the extraction of values from raw materials, have developed under the influence of demands for one or more products and only under ideal conditions, not easily attained, do those demands become balanced so as to cause full value extraction, that is to say, full utilization. Such industries, then, under simple and (industrially) primitive conditions produce one or more main products and waste products. The waste is produced arbitrarily and necessarily, and is discarded in lack of a demand calling for its use. As such industries develop, products of value come to be made from the so-called "waste"; the industry then turning out one or more by-products, in addition to the main product or products, and less waste. But the development of by-products is a slow and lagging growth, so much so that, by and large, an imposing loss of potential value accrues by this default. A fully developed industrial activity produces main products, balanced according to demand; by-products fully developed to current needs; no waste products. There are few activities in the United States that have attained this measure of effectiveness; perhaps the modern packing house is the most conspicuous example we can adduce.

In the course of industrial growth, the production of main products is under the control of a natural law whereby supply and demand seek mutually and automatically to effect a balance against disturbing external factors. The production of incidental products (waste products and by-products), however, is under no such control, but is determined by the output of main products. Hence the supply of incidental products exceeds the demand. Industry itself tends to bring these incidental products into use, but is limited by certain restrictive circumstances.

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[1] The term "multiple product" is used to convey the idea of unlimited range of growth, a conception inadequately expressed by the word "by-product."

[2] This matter is exceedingly involved and complicated and can be presented here in broad outline only. A more detailed study of the rôle of by-products in the mineral industries is in course of preparation for publication later in this series.

The individual industrial activity is often too small or poorly organized to make by-product recoveries, which usually gain their value from a cumulative effect only possible under large-scale operations. If the activity is strong and highly organized it tends to build up by-products, in so far as the by-products are end-products or near end-products; that is, materials that may be adapted by slight treatment to an immediate consumptive demand. Such activities may even add small pendant industries in order to make the adaptation. Such pendant industries, however, are usually confined to operations that may be largely fed by the output of the parent industry.

If, however, the potential by-products are of the intermediate order, requiring outside industries to carry them forward into use, and these outside industries are lacking, inadequate, or too foreign in scope to be built up by the parent activity, the matter of by-product development gets beyond the reach of industrial stimulus. Such is the case with the bulk of by-product possibilities. The parent industry can do little or nothing; independent industries to handle such materials are slow to develop, hampered by the uncertainties of a supply fluctuating independently of the pressure of their demand, and hesitating to build activities at the mercy of conditions beyond their control.[1]

Apart from the virtual inability of an industry to create a favorable outlet for its potential by-products of the intermediate order, there is a lack of definite stimulus to do so, growing out of the fact that the loss involved in nondevelopment is not felt by the industry. Within an industry, it is true, where the lack of by-product recovery is due to the inferior practice on the part of an individual enterprise as contrasted with its rivals, the waste involved does mean financial loss to the activity engaged in the inferior usage, and is slowly remedied by the operation of continued competition. But where the lack of by-product recovery is common throughout an industry, there is no competitive spur toward improvement; and as the waste involved in the lack of full-value recovery is a loss not borne by the industry and not perceived by the public, who for the main products pay a price untempered by by-product contributions to joint cost, there is no activating motive to give the matter initial impetus.

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[1] There are other factors retarding independent industrial developments utilizing by-products, but these involve matters that need not be gone into here.

It would appear, therefore, that by-product developments are under the influence of peculiar economic factors, and therefore demand treatment different from that accorded ordinary industrial affairs. Industrial initiative and competence face distinctive limitations in what they can do alone. These limitations lie in the field of industrial interrelationships, in the no-man's land between industries. These limitations can not be adequately overcome by any single industry; their elimination requires cooperative action, synchronized growth, between one industry and another, frequently, indeed, between a large number of industries of which some may not even be in existence. These delicately balanced intergrowths obviously require a guiding hand of wider sweep than any single industry affords. Here is a true governmental function, an untilled field for constructive economic policy to make productive. Upon this concept hangs the whole forward sweep of by-product development; and as the utilization of raw material is going forward, of necessity, on the basis of by-product recovery, we are here involved in a matter that may not wisely be overlooked.

It need not be considered here how far a constructive economic policy may advantageously go in this matter. But at least it should accord the problem the true weight of its importance, build toward effecting a proportionated industrial growth, gather an accurate record of the so-called waste products turned out by the industries of the country, and encourage the development of new industries utilizing products now going to waste. The lack of a constructive economic policy in the United States has not critically retarded the growth of ordinary industrial activities, in which, indeed, this country holds a foremost place; but it has been unfavorable to the proper development of all those industries involving by-product principles—the chemically controlled industries,[1] as they may be termed for want of a better name—in which this country, in spite of some notable achievements, has fallen notoriously short of her possibilities.

The whole matter of by-products growth has been retarded, also, by the general feeling that it represented a small incidental matter of no great moment.[2] But, as a matter of fact, the sum total of the possibilities embraced is of the most striking import, whether measured in dollars or in service to society. The capability of by-products to lower the cost of main products is perhaps a very direct measure of the public's concern in a policy competent to stimulate progress toward that end. No better example can be brought forward than the following table recently published by a large packing house showing how by-products contribute to lowered cost:[1]

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[1] This term is intended to be broader in scope than the term "chemical industries."

[2] Anyone who has followed the chemical journals for the past few years would see no tendency to underestimate the matter, but these views, unfortunately, seldom reach the public broadly or the general press. Recent war-enforced interest in chemical affairs is changing these conditions slightly.

Average price paid for cattle, per steer	$84.45
Average price received for meat	68.97
Average price received for by-products	24.09
Total received	93.06
Expenses and profit	9.90

As to their social value—their contribution toward human conservation and welfare—modern civilization in the past few years has become utterly dependent upon the aggregate of by-product substances, which have already entered practically every realm of activity. Nay, more than this, civilization at this very moment of writing rests upon the competence of toluol, an obscure by-product of coal and petroleum, scarcely heard of a few years ago.

Applying these conceptions to petroleum, we observe that petroleum refineries at present produce:

	Proportionate bulk.	Proportionate value.
	Per cent.	*Per cent.*
Four main products	About 80	About 90
About 200 by-products	About 15	About 10
Waste	About 5	None.

The petroleum refining activity is the largest and one of the most efficient chemically controlled industries in this country. Yet while the most competent branches of this activity have carried the production of the main products forward with effectiveness, they have not been able, alone, to draw more than a modicum of value from the by-product possibilities inherent in the resource. Aided by a constructive economic policy active in the direction of shaping a proportionated outlet for intermediate products and focusing a competent campaign of chemical research on the matter, the petroleum industry would be enabled to carry its by-product development much further, to the relief of the cost now so exclusively borne by gasoline, kerosene, fuel oil, and lubricants. Petroleum and coal tar are the chief raw materials of synthetic organic chemistry, and the values hidden in these two substances, as already so well known in the case of coal tar, can not be exaggerated in prospect.[2]

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[1] Swift & Co., 1918 Yearbook, p. 32. This expression, of course, is conservative.

[2] Apart from the matter of by-products, the automotive industry can assist in maintaining a balanced outlet for the main petroleum products by bending its technical developments so as to fit the resource in the way of adapting its engines to handle a wider range of oils.

Encouragement of oil-shale development.—Although the present source of petroleum should be made to render its fullest service, we should at the same time find out what is going to take its place and prepare in advance for the transition, not ignoring the matter until it is forced by sheer necessity.[1] We have already seen that oil shale is the only successor in sight, and indeed some attention has already been devoted to this resource, especially as the richest part of it occupies land in possession of the Government.

But oil shale being a leaner resource than that now worked for petroleum is not a rival but an understudy to the oil field. A shale-oil industry will come into life when the situation is ready for its advent. A constructive economic policy will neither force its premature birth nor will it permit conditions to retard its inception and growth when once its help is needed to supplement an inadequate oil-field production. The oil-shale matter, then, is merely part of the whole oil problem and can not be solved on its own merits alone. Indeed, it has no merits other than those reflected from a growing scarcity of petroleum.

The oil-shale development will have to unfold under the influence of an economic necessity for shale oil. A constructive policy may contribute to that unfoldment in three ways, but further than that it can scarcely go safely or wisely.

It can, in the first place, stabilize the production of petroleum so as to place this resource on the sound basis of ordinary mining procedure. With this done, oil shale will face a resource with which it can cooperate, not an adversary which it must fight. So long as the oil fields of the country fill all the legitimate needs for petroleum products and contribute a large surplus for burning under boilers, there would appear to be no pressing need for shale oil.[2]

Secondly, the Government can prepare for the time when shale oil will be needed [3] by establishing an experimental plant on a commercial scale, equipped to work out on a practicable basis, with full by-product recovery, the most efficient practice adapted to the conditions of the domestic resource. Such a plant could start with the technique developed in the Scottish shale-oil industry, and by proper research build up a process which would insure the home activity from taking over any obsolescent features of the Scottish practice or from passing through a stage of technological immaturity. This step, too, by providing exact figures of cost would give needed information upon which plans for an industrial development could be built. With the petroleum situation under scientific guidance throughout, and the shale-oil process worked out, the successor to petroleum could come into action on the sound basis of engineering exactness, unencumbered by the speculative element of uncertainty.

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[1] We must remember that this country, thus far, has never had to face the exhaustion of a great resource. A somewhat analogous experience is afforded, however, in the case of the virgin forests.

[2] It is obvious that oil shale, to be profitable, must yield a full complement of products. There is still an oversupply of petroleum in respect to that consideration. An artificially stimulated or premature production of large quantities of shale oil would encourage the perpetuation of the current wasteful method of exploiting petroleum.

[3] That need has been temporarily brought into the present by circumstances arising out of the war (see pp. 35–39).

In the third place, as most of the richest oil-shale areas are embraced in the public lands, the Government has the responsibility of either itself developing the resource or of delegating this duty to private industry. Since governmental operation of matters in the field of legitimate industry is outside the favor of public opinion, it is evidently necessary that the resource be made available to private development under terms favorable both to the industrial activities concerned and to the public at large. To this effect, it will be the function of an adequate administration of the matter to hold such lands open to legitimate development leading to production, but guarding them against entry for purposes of speculation or non-producing investment. This, in fine, will hold the resource receptive to the real need, when it comes, keeping the field free of hampering encumbrances. It is feasible to frame legislation at once that will advertise the fact that the oil-shale lands are definitely open for productive operations, but are not available under conditions of deferred or non-production. As to the size of operations, it should be borne in mind for the purposes of such legislation, that while well-rounded integration is not essential to oil shale in the same degree that it is in respect to petroleum,[1] effective operations will require a considerable outlay and hence should not be shaped arbitrarily to a meager scale.

Encouragement of benzol and alcohol development.—While there is no apparent need at the present moment for gasoline to be relieved of part of its duties by the production of substitutes such as benzol and alcohol, these products are now running to waste because of the lack of that need. Each year we are wasting—destroying—vast resources capable of producing motor fuel, because they are a little less convenient to utilize than the petroleum resource, although the latter is strictly limited in size. Only an inadequate policy would permit such sacrifice of ultimate value to the expediency of the moment, although such a procedure is of such common experience as to be looked upon as an economic necessity and hence justifiable. An analogy is afforded in the case of water power, which is still largely unused on the assumption that coal is plentiful and hence that there is no need for water-power development; the blind adherence to this dictum, ignoring its inevitable bearing upon transportation, has probably caused sufficient disaster to arouse suspicion of its wisdom.

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[1] With oil shale the elements of wildcatting and competitive extraction are lacking; hence there is no necessity for haste of production, with its consequent waste. Also the conditions of shale-oil production can not support sustained overproduction, as with petroleum. There is no need, therefore, to adjust size of holdings to geological units.

A constructive economic policy, then, will not ignore benzol and alcohol, but on the contrary will promote their use. Benzol, indeed, demands such consideration on its own account, for a market for this product must be built up to help carry forward the important matter of proper coal utilization, as explained in the paper, "Coal: The Resource and its Full Utilization."[1] Alcohol, too, is not without claim on grounds outside the petroleum interest, for its fuel utilization would give an outlet to the growing number of distilleries going out of service, while its possibilities as to generation on farms and its peculiar adaptability to tropical conditions form considerations of considerable weight. But for the sake of the petroleum resource itself, it would not be unwise to bring some relief to the growing demand for gasoline, which unhelped must face eventual curtailment.[2]

SUMMARY.

The petroleum resource stands out because of its limited size and decreasing availability, the growing importance of its products, and the notoriously high percentage of waste involved in its exploitation. According to conservative estimates, scarcely 10 per cent of the resource value is recovered under present conditions, while the unmined supply now available in the United States is only about 70 barrels to the person. A survey of the resource and of the industrial activities engaged in its development indicates that the bottom cause of the present wasteful employment of this invaluable resource is a lack of adjustment between economic circumstances affecting production, and the unique geological conditions under which petroleum occurs. The geological unit or reservoir, by nature indivisible, is arbitrarily subdivided into small parts for purposes of individualistic production. This discordance leads to a train of wastes that consume the bulk of the resource. Its cause may be removed by reshaping the method of production so as to fit with the occurrence of the resource, and the means for this accomplishment will come through development and application of a constructive economic policy.

The betterment of the situation, in the last analysis, depends upon the pressure of public opinion. The whole matter now rests upon an unsound basis. The exploration for petroleum is guided by the principle of gambling. The extraction of petroleum is dominated by the principle of robbery.[1] The utilization of petroleum is conditioned, in part, by the principle of perversion. Society has put its ban upon these principles as applied to superficial matters. How long before their unsoundness will be recognized in respect to a basic necessity of life?[2]

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[1] Bulletin 102, part 4.

[2] It may not be beyond the interest of the automotive industry to bend its energies toward providing a situation where benzol and alcohol will come into action. Such effort, if undertaken, should merit popular support because of its constructive tendency; and in particular will it stand in need of sympathetic governmental help when it approaches the legal aspects of alcohol exemptions.

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[1] Not *robbery,* but the *principle of robbery;* competitive extraction of petroleum within single reservoirs is legalized and in good repute.

[2] The writers desire to acknowledge their indebtedness for valuable information to the publications of the U. S. Bureau of Mines and the U. S. Geological Survey, as well as to personal communications from many individuals, including Carl H. Beal, Chester Naramore, John D. Northrop, David T. Day, H. S. Dennison, and R. D. George.

PUBLICATIONS OF THE DIVISION OF MINERAL TECHNOLOGY, U. S. NATIONAL MUSEUM.

Publication 2421, Smithsonian Institution. Sources of nitrogen compounds in the United States, by Chester G. Gilbert. Issued June 30, 1916. 12 pp.

Nitrogenous compounds are essential not only to self-defense but to the country's capacity for self-support, and to be effective the source must be such that the products may be adaptable to meet either requirement. This paper reviews the merits of the three principal processes for manufacturing nitrogen compounds from the atmosphere, with the following conclusion: The arc method has not thus far demonstrated capacity to meet the agricultural requirement at all, or even the defense requirement efficiently. Definite knowledge concerning the Haber process is lacking, but its record of achievement is against it, and it would seem, moreover, unsuited to American conditions, at least in the present state of its development. The cyanamid process is capable of a development which will meet the requirements for a cheapened nitrogenous fertilizer source whose form of nitrogen content is readily convertible to nitric acid. The process is already a prominent factor in the economic well-being of most countries of older civilization and is capable of similar extension in the United States.

Bulletin 102, part 1. Coal Products: An object lesson in resource administration, by Chester G. Gilbert. Issued November 17, 1917. 16 pp., 11 pls.

The chemical industries of this country are notoriously weak; in fact, up to the outbreak of the present war we had relatively few chemical industries, yet no field of industrial activity is more essential to the country. The most important of all the chemical industries is that represented in the manufacture of coal products. The purpose of this paper is to bring out the reason for the lack of the chemical industries in general and the coal products one in particular, with a view to determining where the fault lies and what should be done to correct it.

Bulletin 102, part 2. Fertilizers: An interpretation of the situation in the United States, by Joseph E. Pogue. Issued October 10, 1917. 22 pp., 1 pl.

The fertilizer resources of the United States are viewed in the light of their importance under war-time conditions, when, on the one hand, an increasing supply is needed for the production of an added output of foodstuffs, and, on the other, the foreign sources of supply from which much of our mineral fertilizer is drawn have been cut off or endangered. The rather remarkable circumstance that this country has been dependent upon Chile for nitrogen, upon Germany for potash, and upon Spain for pyrite used in the manufacture of sulphuric acid, is pointed out in respect to developing national independence as regards these fundamental materials. The paper is accompanied by a chart which shows in one expanse the whole fertilizer situation, with particular regard to the effects of the war upon it. The purpose of the paper is to emphasize to the general public as well as to those more directly interested in fertilizers the importance of dealing with this matter as a broad and fundamental problem affecting the basic matter of food supply.

Bulletin 102, part 3. Sulphur: An example of industrial independence, by Joseph E. Pogue. Issued November 7, 1917. 10 pp., 1 fig., 3 pls.

Two sulphur deposits near the Gulf coast in Louisiana and Texas, worked by an ingenious and efficient mechanical process, not only are supplying practically all of the crude sulphur in this country, but their development has shifted the world's largest sulphur industry from Sicily to the United States. The geological occurrence and method of working the Gulf deposits by means of the Frasch process are described in nontechnical language. The bearing of these deposits on the sulphuric acid situation is discussed and the need pointed out for a determination of the sulphur resources present in the whole Gulf region, with a view to defining a proper adjustment between the needs of the sulphur industry and the sulphuric acid industry.

Bulletin 102, part 4. Coal: The resource and its full utilization, by Chester G. Gilbert and Joseph E. Pogue. Issued February 21, 1918. 26 pp.

The cost of fuel in the home is roughly four or five times the first cost at the mine. In other words, the cost to the consumer is out of all proportion to the price at the producing end. This discrepancy means an extravagant price for fuel in the home and is due to wastefulness of economic procedure all the way down the line between production and consumption. It is the purpose of this paper to analyze the situation and point out economic changes needed to better conditions.

Bulletin 102, Part 5. Power: Its significance and needs, by Chester G. Gilbert and Joseph E. Pogue. (In press.)

In this country tremendous emphasis is placed on the use of power; the result is a growing burden on transportation which must be solved. The present transportation difficulty is in a measure an expression of this problem. The purpose of this paper is to develop the general nature of the situation and suggests the character of remedial action called for.

Bulletin 102, Part 6. Petroleum: A resource interpretation, by Chester G. Gilbert and Joseph E. Pogue. Issued 1918. 74 pp., 12 figs., 3 pls.

Petroleum is of particular significance because, of all our important resources, it is the most limited and involves the highest percentage of waste. Scarcely one-tenth of the value of the resource is recovered under present circumstances, while the unmined supply available under current practice is only about 70 barrels to each person. This paper makes an economic study of the resource and the industry engaged in its development, and traces the causes of waste to certain maladjustments in the economic situation, pointing out how these may be remedied by a constructive economic policy applied to the matter. The desirability of developing shale oil to replace petroleum as it becomes incapable of meeting the demand is gone into and the advisability of using benzol and alcohol as substitutes for gasoline is considered. The natural gas industry is also treated.

NOTE.—The papers listed above as parts of Bulletin 102 are members of a series entitled "The Mineral Industries of the United States."

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SMITHSONIAN INSTITUTION
UNITED STATES NATIONAL MUSEUM
Bulletin 102, Part 7

THE MINERAL INDUSTRIES OF THE UNITED STATES

NATURAL GAS: ITS PRODUCTION, SERVICE, AND CONSERVATION

BY

SAMUEL S. WYER
Of Columbus, Ohio

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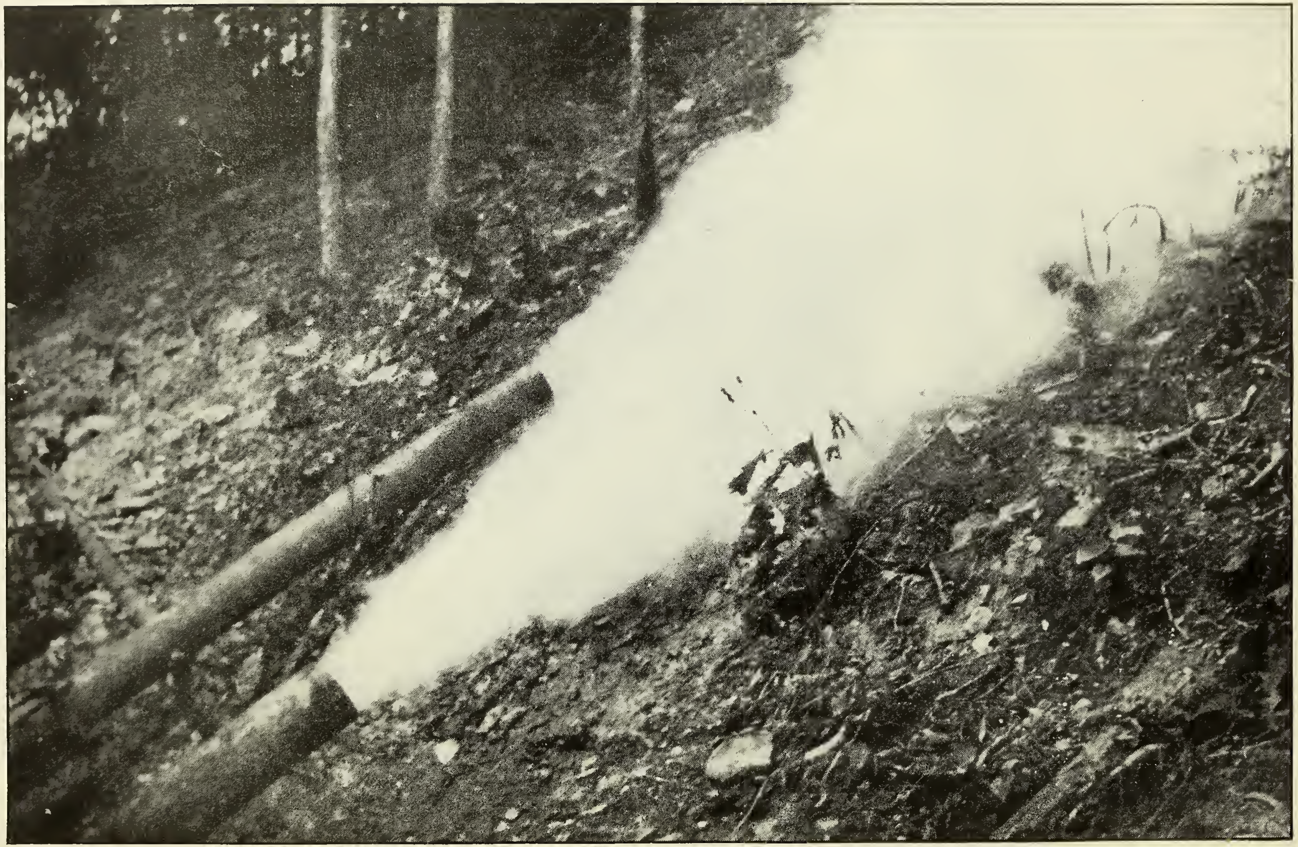
1918



GAS WASTE IN KELLY'S CREEK FIELD NEAR CHARLESTON, W. VA.

Two 4-inch lines on hillside, blowing at least 5,000,000 cubic feet of natural gas into the air in order to get oil. This is due to competitive conditions, carelessness in operation, and the popular attitude that natural gas is not worth saving.

SMITHSONIAN INSTITUTION
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FOREWORD.

Natural gas is the least appreciated, consequently the most abused, of the mineral resources in popular use. The issues involved are of direct concern to some ten millions of the inhabitants of the United States, and their range of influence does not stop even here; for they form a prominent feature in the nation-wide problem of fuel supply which may be solved effectually only through coordinated attention to the component parts. This problem science and technology, working together, can take the initiative in simplifying, by pointing the way and devising means for its solution, but of their own initiative, they are powerless to go further. The responsibility of initiative in carrying forward the actual process of solution rests with the public, and resting with the public is contingent, as a first requisite, upon public opinion genuinely alive to the situation. This condition of affairs, naturally, is most pronounced in industrial connections of the public service order to which the activities comprising the natural gas industry belong; and this particular situation, bad enough from environment, is further aggravated by characteristics inherent in the resource.

The public must look to remedying the situation or within a very few years lose the services of the resource already seriously impaired. The stimulus to action contributed in the form of technical discussions is inadequate and equally so that afforded in appeals to sentiment and sensationalism. The United States National Museum has undertaken the preparation of an exhibit designed to visualize the situation in its true bearing, and the normal order of precedence would be to follow this with publications drawing upon the exhibit. In view of the present emergency, however, with its effect on the question of fuel supply, it is deemed best not to wait upon ceremony but to publish the present paper by Mr. S. S. Wyer, without the delay which would otherwise occur.

The situation is too complex for any simple formula of remedy. It is not only complex but acutely critical as well, and needs all the light that can be thrown on it from all sides. This particular discussion sets forth the technical issues as viewed by a practical engineer who alone is responsible for it in a concise, readable presentation which makes it a distinct contribution toward clarifying the situation.

C. G. Gilbert,
Curator, Division of Mineral Technology,
United States National Museum.

TABLE OF CONTENTS.

Page.
Fundamental principles of natural gas production ... 7
  How natural gas is mined and served to the consumer ... 7
  Definition of lease ... 8
  Reserve acreage ... 8
  Distinction between acreage lease rentals and gas well royalties ... 9
  Fundamental conception of gas ... 9
  Cause of gas pressure ... 10
  What makes gas flow ... 10
  Definition of natural gas ... 10
  Definition of "mechanical mixture" ... 11
  Definition of term "vapor" ... 11
  Gases and vapors distinguished ... 11
  Natural gas may be wet or dry ... 12
  Wrong impression of word "natural" ... 12
  Natural gas a mineral ... 13
  Origin or formation of natural gas ... 13
  Starting point of gas activity ... 13
  Barometric pressure ... 14
  Gage pressure ... 14
  Absolute pressure ... 14
  Differential pressure ... 15
  Effect of pressure on gas volume, known as Boyle's Law ... 15
  Effect of temperature on gas volume, known as Charles' Law ... 16
  Gas sand or gas rock ... 16
  Definition of rock pressure ... 16
  Why rock pressure and volume must decline ... 17
  Regeneration ... 18
  Storage of natural gas ... 19
  Limits of geology ... 19
  Limits of underground reservoirs ... 19
  Open or natural flow ... 19
  Misleading well capacity ... 20
  Migratory and fugitive nature of natural gas ... 20
  Extent of natural gas underground drainage ... 21
  Quality and quantity of natural gas fixed by nature ... 21
  Scarcity of natural gas ... 21
  Natural gas service is based on a noncreatable and nonregenerative mineral. 23
  Natural gas service and oil business distinguished ... 24
  Drying natural gas ... 25
Principles of natural gas transmission ... 27
  Transmission is more than mere transportation ... 27
  Why natural gas is compressed ... 28
  How natural gas is compressed ... 28
  Status of gas compressor art ... 29
  "Gas compressing" and "gas pumping" ... 29
  Rock pressure decline lowers compressor capacity ... 29
  Size and cost of lines necessary without compressors ... 29
  No heat loss in natural gas compression ... 30
  Not feasible to make natural gas main lines common carriers ... 30
Natural gas distribution ... 34
  Natural gas is a service, not a commodity ... 34
  Why gas consumers use more natural gas than manufactured gas ... 34

Natural gas distribution—Continued.

Page.
Peak load service ... 35
Peak loads increase cost of service ... 36
Basic reasons for large sales of industrial gas ... 37
Peak load conditions analogous to strap hanger problem ... 38
Use of auxiliary heating appliances ... 40
Few improvements in art of using natural gas ... 40
Cooking and heating distinguished ... 40
What is usable natural gas pressure ... 41
Accuracy of meter registration at low and various gas pressures ... 42
Effect of gas pressure on gas leakage ... 42
Gas meter facts ... 42
Distinction between luxury and necessity in natural gas service ... 43
Consumer is responsible for economic use of gas ... 43
Barometric changes make more difference on total pressure than gage pressure variation ... 44
Atmospheric temperature changes heating value of gas more than changes in gage pressure ... 44
Effect of pressure or temperature changes on heating value of gas ... 44
Combustion of natural gas ... 46
Effect of atmospheric temperature on demands for gas ... 47
Daily demands for gas heating service ... 47
Monthly demands for gas heating service ... 48
Why standards for natural gas service must be lower than for manufactured gas ... 48
Discount for lower pressures stimulates waste ... 49
Extension of service ... 50
Waste and conservation of natural gas ... 51
Definition of conservation ... 51
Extent of waste ... 51
Specific forms of waste ... 52
Drilling wastes ... 52
Well operation wastes ... 53
Transmission wastes ... 53
Utilization wastes ... 54
Definition of "offset well" ... 55
Drilling offset wells may make existing wells commercially worthless ... 56
Why offset wells are frequently dry ... 56
Why offset wells are frequently of low capacity ... 56
When is the drilling of offset wells justifiable? ... 57
Public pays for wasteful operation ... 57
Gas leakage ... 58
Definition of carbon black ... 59
Waste in carbon black manufacture ... 59
Why carbon black manufacture may be more attractive than public utility service ... 60
Small capital in carbon black plant as compared to public utility plant ... 61
Competition always economic waste ... 62
Ease in drilling invites competition ... 62
Critical need of the natural gas industry ... 62
Effect of governmental opposition to unified control ... 63
Pooling of field operations mandatory if waste is to be reduced ... 63
Provincial thinking cause of most natural gas waste ... 64
Characteristics of natural gas prospectors and new gas supplies ... 65
Conservation of natural gas possible only with profitable operation ... 65
When is it commercially feasible to conserve gas or develop new supplies? 65

NATURAL GAS: ITS PRODUCTION, SERVICE, AND CONSERVATION.

By Samuel S. Wyer.
Of Columbus, Ohio.

FUNDAMENTAL PRINCIPLES OF NATURAL GAS PRODUCTION.

HOW NATURAL GAS IS MINED AND SERVED TO THE CONSUMER.

The first step is the securing of the lease or right to prospect for, reduce to possession, remove and market natural gas. This lease must usually be secured, held, and paid for, for a number of years—on the optimistic but unproven faith that it may contain gas—prior to beginning actual development work.

The unknown underground supplies of natural gas are found and reduced to possession by drilling down from the earth's surface. To protect the hole, an iron pipe—called a "casing"—is driven down into the rock formation always found above the gas-bearing sand rock. A plugging device known as a "packer" is fastened in the casing or hole in the rock, immediately above the gas formation, and the gas by virtue of its inherent expansive tendency then comes to the surface—usually about one-half mile above—through tubing, as shown on page 8, and forces itself into the transmission lines, when it then may continue by its own expansive force to travel on toward the consumer.

As the gas travels the pressure must drop, for the reasons given on page 10, and this necessitates the installation of gas compressors, whose function is to recompress the gas, increasing thereby its pressure, so that it will continue to travel through the transmission lines. From the compressing station the gas then goes to the consumer. When the gas reaches the distributing plant it passes into the medium pressure lines in the city and the pressure is then in turn reduced to the low-pressure lines, where it travels through the mains at probably 5-ounce pressure to the square inch—this, of course, constantly decreasing as the consumer's fixtures are approached—through the service cock, service line, consumer's meter, consumer's piping, and ultimately is burned at the consumer's fixtures.

These steps present an unbroken chain of service features, from the reserve acreage in the field—that must be carried and paid for in order to permit of future drilling operations, and, therefore, future service—to the consumer's fixtures, with this additional feature, that when the gas passes the consumer's meter it is reduced to possession by him, becomes his personal property, under his absolute control, and he can do with it what he pleases.

DEFINITION OF LEASE.

A natural gas lease is a contract for a consideration establishing a vested right to enter upon a definitely described parcel of land, for a determined period, to prospect for, reduce to possession, remove and market natural gas. The vested right is the crux of the whole matter, and it is immaterial whether the instrument creating it is called a " lease," " contract," "grant," or " deed of conveyance."

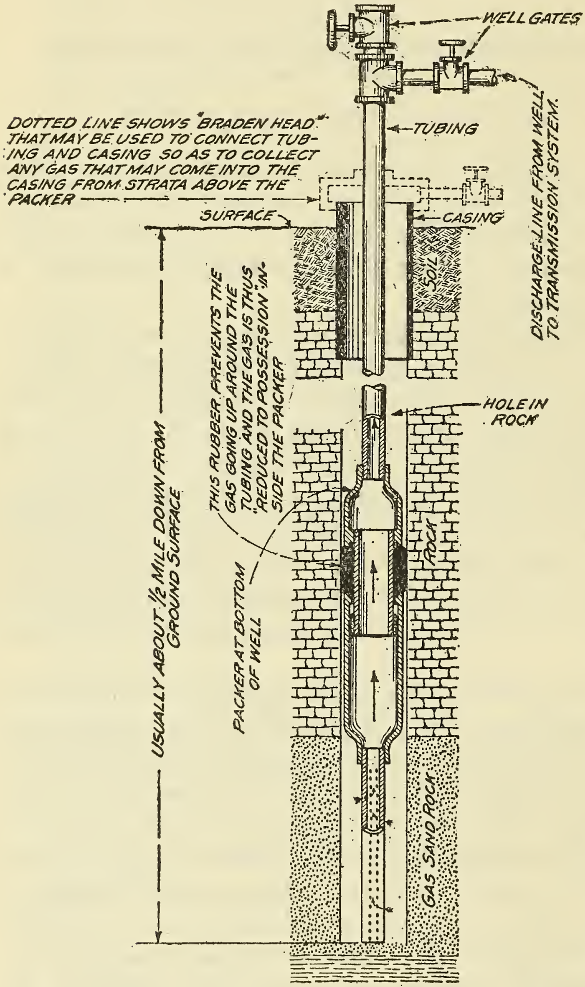
WELL GATES
DOTTED LINE SHOWS "BRADEN HEAD" THAT MAY BE USED TO CONNECT TUBING AND CASING SO AS TO COLLECT ANY GAS THAT MAY COME INTO THE CASING FROM STRATA ABOVE THE PACKER
TUBING
DISCHARGE LINE FROM WELL TO TRANSMISSION SYSTEM.
SURFACE
CASING
SOIL
USUALLY ABOUT ½ MILE DOWN FROM GROUND SURFACE
THIS RUBBER PREVENTS THE GAS GOING UP AROUND THE TUBING AND THE GAS IS THUS "REDUCED TO POSSESSION" INSIDE THE PACKER
HOLE IN ROCK
ROCK
PACKER AT BOTTOM OF WELL
GAS SAND ROCK

Fig. 1.—Diagram showing how natural gas is reduced to possession.

In a given tract of land it is always a matter of doubt to what extent, if any, mineral may exist in paying quantities, until very considerable development work has been performed, which requires in most instances large expenditure of capital. For this and other reasons, a custom long ago arose for the owner of supposed mineral land to grant to a mine operator the right to enter upon the land and search for and extract mineral, and the form which the contracting parties pretty generally adopted to express their agreement was a " lease," which purported to entitle the " lessee " to occupy such part of the premises as was necessary to carry on his mining operations, and to use, mine, and extract the minerals therefrom. (Lindley on Mines, ed. 3, p. 2134.)

RESERVE ACREAGE.

Based on the United States Geological Survey statistics for 1916, natural gas producers in this country carry an average of 313 acres for each producing well, in their attempt to provide as far as possible continuity of service to their customers. However, this average of 313 acres will vary with different fields and localities. In West Virginia the United Fuel Gas Co. in 1917 carried 1,252 acres to the producing well, as shown on page 24. From this it is evident that not every farmer—that is, landowner—can have a producing well, even though his farm may be located in the center of producing territory. While natural gas wells are frequently drilled on tracts of less than an acre in area, by small producers intent only on getting the gas out in the fastest possible manner, without any regard to future service, the future continuity of service to the gas-using public is possible only by the carrying of reserve acreage for future drilling operations.

DISTINCTION BETWEEN ACREAGE LEASE RENTALS AND GAS WELL ROYALTIES.

The general custom of the natural gas business is to pay a lease rental based either directly on indirectly on the acreage of the tract that is controlled. The natural gas acreage statistics of the United States Geological Survey for 1916 show that—

5 per cent of acreage is owned in fee.
8 per cent of gas rights are owned in fee.
87 per cent of gas rights are merely under lease.

This acreage rental covers a twofold object—

1. Gives the gas company the right to enter the particular tract of land for exploration purposes.
2. Pays the farmer—that is, landowner—for any gas that might be found on such tract, even though such gas would be removed by drainage through to wells located on adjacent tracts.

Well royalty is merely compensation for particular wells drilled, and replaces the acreage rental that prevailed prior to the drilling of the wells. The well royalty for a particular tract is usually larger than the aggregate of the acreage rental because of the damages and inconvenience to the farmer in having wells and their appurtenances located in his fields.

It is not ordinarily appreciated that the total amount of money paid for "acreage rental" is larger than for "well royalties." Thus, the acreage rental of the United Fuel Gas Co. for the year 1917 was 80 per cent of the total annual sum spent for gas rights.

FUNDAMENTAL CONCEPTION OF GAS.

Gas is a fluid composed of a large number of molecules which are vehicles of energy continually in motion and having an inherent tendency to get farther and farther apart. The range of motion of the molecules is limited only by the volume of the closed containing vessel in which they constantly move to and fro. Every molecule possesses the inherent power of energy and is eternally energetic within itself. That is, the molecules are in a state of constant bombardment against each other and against the sides of the containing vessel. The most distinguishing characteristic of gas is its universal property of completely filling an inclosed space.

CAUSE OF GAS PRESSURE.

Gas pressure is the result of the combined efforts of all the moving molecules in the gas trying to get farther and farther apart; that is, a mass of gas inclosed in a vessel expands and fills it, and, being restrained from further expansion, it exercises a pressure against the walls of the vessel. This pressure is the same in all directions on equal areas of surface. Not only is every gas molecule eternally energetic but its energy may be augumented or retarded by external conditions. Contracting the volume of gas increases the intensity of its internal molecular motion and therefore increases its pressure. Conversely, expanding the volume of a given mass of gas decreases the intensity of its internal molecular motion and therefore decreases its pressure. That is, with a given mass of gas any increase in volume of containing vessel will give the molecules more range of motion and thereby lower the pressure. Thus, if a part of a given mass of gas is removed from a closed vessel or reservoir the remaining mass of gas will expand instanter and keep the vessel or reservoir filled, but at a lower pressure.

WHAT MAKES GAS FLOW.

The inherent tendency of gas to expand is the basic cause of gas flow. Gas flow in pipes or underground reservoirs can not take place except between openings of higher, to openings of lower pressure; that is, flow can be obtained only by sacrificing pressure. This is in accordance with the universal natural law that as long as energy of any form undergoes no transformation it tends to gravitate to a lower degree of intensity—that is, becomes more stable and approaches a universal level of stable equilibrium. Thus, water always seeks the lowest level, and confined gas always tends to expand to lower pressures. Even where gas compressors are used to increase the pressure by contracing the volume, the gas is not pushed through the pipe like a plug of incompressible fluid, like oil or water, but goes through by virtue of the increased expansive force resulting from the higher pressure.

DEFINITION OF NATURAL GAS.

Natural gas is a highly combustible gas made by a secret process of nature. It is not a chemical compound—as popularly supposed—

but a mechanical mixture of several combustible and diluent gases and vapors thoroughly diffused through each other, the number and exact proportion of the various crude natural constituents varying for the different localities and somewhat during the working lives of individual wells.

The term "casing-head gas" is applied to a natural gas that flows from oil wells, coming out between the casing and tubing. It is collected by means of a metal head—called "braden-head"[1]—connecting the casing with the tubing, as shown by the dotted lines at the top of fig. 1. The term "braden-head gas" is sometimes used synonymously for casing-head gas.

DEFINITION OF "MECHANICAL MIXTURE."

This is a mixture where two or more substances are brought together in a thoroughly commingled state, without, however, any of the constituent substances losing their individual identity. The various vapors and gases going to make up natural gas are merely intermingled as mechanical mixtures. Another very common illustration is atmospheric air, where water vapor and the gases oxygen and nitrogen are merely mixed in the form of a mechanical mixture; that is, the water vapor has undergone no chemical change and the oxygen and nitrogen have undergone no chemical change by the mixture.

DEFINITION OF TERM "VAPOR."

This word literally means a warm exhalation. A vapor is the gaseous state of a substance which at ordinary temperature exists as a solid or liquid; that is, the vapor is the result of the action of heat on a solid or liquid. On removal of the heat the vapor will return to its former solid or liquid state. When a liquid, by the action of heat, goes into a vapor or gaseous form it is said to vaporize or evaporate, the meaning of these two terms being the same. The most common form of vapor is the moisture always present in greater or less degree in the atmospheric air.

GASES AND VAPORS DISTINGUISHED.

A vapor is an aeriform substance in the gaseous state at any temperature below the critical point, the critical point being the line of demarcation between a vapor and a gas. The temperature of fluid at the critical point is the critical temperature, and the pressure which at this critical temperature just suffices to condense the gas to the liquid form is called the critical pressure. A vapor can be reduced to a liquid by pressure alone, and may exist as a saturated vapor in the presence of its own liquid. A gas is the form which any liquid assumes above its critical temperature, and it can not be liquefied by pressure alone, but only by its combined pressure and cooling. All vapors are gases, but not all gases are vapors. The difference between vapors and gases may be summarized as follows:

---

[1] Named after its designer Mr. Glenn T. Braden.

Aeriform fluids.

Vapor.	Gas.
Below its critical temperature and pressure.	Above its critical temperature.
Can be condensed by pressure alone.	Can be condensed only by both pressure and cold.

Gasoline found in natural gas always exists there in the form of a vapor, while methane, for instance, in natural gas exists only as a gas.

NATURAL GAS MAY BE WET OR DRY.

Natural gases coming from the ground may be classed—according to their gasoline vapor content—into two main groups, namely:

1. *Wet gas.*—This is gas intimately associated with oil, usually produced with oil, and is ordinarily known as casing head natural gas.

2. *Dry gas.*—This is gas not intimately associated with oil, but may nevertheless contain gasoline vapors. The term "dry" does not refer to water vapor that may be carried by the gas, but rather to the gasoline vapor, and, furthermore, this is a relative term since a strictly dry gas would be one containing no gasoline vapors.[1]

WRONG IMPRESSION OF WORD "NATURAL."

While natural gas is a natural product made by nature, it is no more natural than other minerals, like coal, oil, or iron ore. The word "natural" came into common use probably as contrasted with manufactured gas, and the use of the word appears to have given a fallacious impression that natural gas was a free and unlimited resource. Merely being made by nature does not mean that a substance is cheap and of low value. Natural gas is a natural resource, which men have learned to use for the satisfaction of their wants. The misconception regarding the position of natural gas has arisen from failing to appreciate that man creates no new matter and can merely get the materials of nature ready for consumption. Food, clothing, wealth in all its forms, are derived originally from nature. The forces of nature, working through the ages, have created things which mankind needs. Human effort expended on these products of nature, converts them into forms which are usable.[2]

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[1] For further discussion, see Bureau of Mines Bulletins No. 88 and No. 120.

[2] Suggested by Ely's Outlines of Economics.

NATURAL GAS A MINERAL.

Broadly, the word mineral means the inorganic materials of which the earth consists. "The word minerals in the popular sense means those inorganic constituents of the earth's crust which are commonly obtained by mining or other process for bringing them to the surface for profit." That is, the term "mineral" is not, *per se*, a term of art or trade, but of general language, and in addition to its broad scientific meaning is also used in a commercial sense where it may include any inorganic substances found in nature, having sufficient value, separated from its condition as a part of the earth, to be mined.

Natural gas is now universally classed as a mineral. However, on account of its adventitious origin, migratory habits, and fugitive tendencies, it is regarded as a mineral with special attributes. Since it is a mineral, it is, therefore, a crude product. As so aptly stated by the United States Supreme Court, "Natural gas is a crude mineral, not advanced in value or condition by refining or grinding or by any other process of manufacture."[1]

ORIGIN OR FORMATION OF NATURAL GAS.

How, when, and where the constituents of natural gas were formed is not definitely known. For our purpose we need not bother about the various theories that have been propounded regarding the origin or formation of petroleum generally or natural gas constituents in particular. That is, whether these constituents originated from cosmic, organic, inorganic, animal, vegetable, volcanic, animal bacterial, plant bacterial, diatomic, or fatty algal sources is not germane. Neither is the matter of adventitious and migratory or indigenous and accumulative relationship with regard to any geological formation of vital importance.

The incontrovertible facts are that we have in natural gas a crude natural substance made up of mixtures of widely varying constituents—even though we may not know how these mixtures were thrown together—for different natural gas fields in the United States. Some of these natural gases are wet, while others are dry; some are high in heating value, while others are low, and some are heavy, while others are light in weight.

STARTING POINT OF GAS ACTIVITY.

As far as temperature is concerned, gas activity begins at a point 460° below zero on the Fahrenheit scale, and as far as pressure is concerned, it begins at the point of absolute vacuum, or 14.7 pounds below atmospheric pressure at sea level. Neither point has ever been reached by man's physical senses, but both form the bases from which all gas volume calculations must be made as shown on pages 15 and 16.

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[1] United States *versus* Buffalo Natural Gas Fuel Co., 172 U. S., p. 339.

BAROMETRIC PRESSURE.

Atmospheric pressure is measured by a barometer—usually in inches of mercury, 1 inch of mercury equaling 0.49 pound to the square inch pressure—and is synonymous with barometric pressure.

Sea level is the basis from which atmospheric pressures are reckoned. At that point dry air at 32° Fahrenheit exerts a pressure of 14.7 pounds to the square inch.

This pressure varies with altitude and temperature, the pressure decreasing with an increase in altitude or temperature. 14.4 pounds represents a fair average barometric pressure for most natural gas using communities.

GAGE PRESSURE.

This is simply the pressure indicated by a pressure gage. Two general classes of gages are used for measuring gas pressure:

1. *Spring gages.*—Where the effect of the pressure exerted against some form of spring is made to move a pointer over a graduated dial or scale.

2. *Fluid gages.*—Where the effect of the pressure is indicated by the height of the column of fluid in a U-shaped tube. One side of the U-shaped tube is open to the atmosphere and the other is attached to the pipe where the pressure is to be measured. The gas pressure in this pipe then lowers the fluid in one side of the tube and raises it in the other. The total difference in the heights of the fluid on the two sides represents the total fluid pressures. When no pressure is applied to such a U tube gage other than the prevailing atmospheric pressure, the liquid will stand at the same level in both tubes.

The pressures in natural gas distributing plants are almost universally measured in ounces to the square inch, while the pressures in manufactured gas distributing plants are measured in inches of water, 1 ounce equaling 1.73 inches of water.

Where the word pressure occurs in ordinances or rules it invariably means gage pressure.

ABSOLUTE PRESSURE.

This is the sum of the gage pressure and the barometric pressure. Thus, if the gage pressure is 4 ounces—equaling 0.25 pound—and the atmospheric pressure 14.4 pounds to the square inch, the absolute pressure will be 14.65 pounds to the square inch, as shown on p. 15. This must be used in all gas calculations dealing with change of volume due to effect of pressure.

Failure to appreciate that the absolute pressure, rather than merely the gage pressure, must be used when computing the effect of pressure on gas volume, or heating value content, has been responsible for most of the misunderstanding regarding the effect of variation in gage pressure on gas quality and gas service.

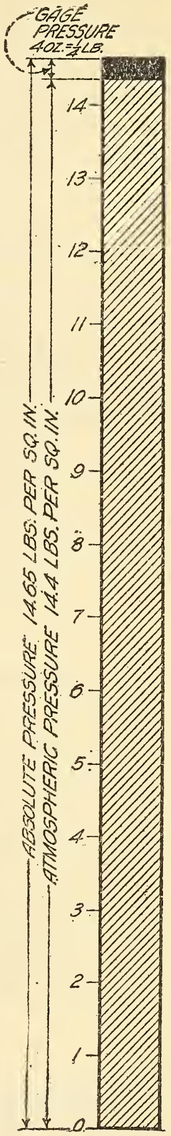
GAGE PRESSURE 4 OZ. = 1/4 LB.
ABSOLUTE PRESSURE 14.65 LBS. PER SQ. IN.
ATMOSPHERIC PRESSURE 14.4 LBS. PER SQ. IN.
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0

FIG. 2. — DIAGRAM SHOWING RELATION OF ATMOSPHERIC AND GAGE PRESSURE.

DIFFERENTIAL PRESSURE.

This is simply the difference between the pressure at the inlet and outlet of a gas line. Thus, if the inlet gage pressure of a gas line were 50 pounds and the outlet gage pressure 10 pounds the differential pressure would be 40 pounds. In gas transmission it is necessary to have a differential pressure in order to secure driving power to force the gas through the line. That is, the differential pressure is the pressure that is lost in overcoming the friction of the gas moving through the line.

EFFECT OF PRESSURE ON GAS VOLUME, KNOWN AS BOYLE'S LAW.

There is a definite relationship existing between the volume and pressure of natural gas. That is, when the gas is compressed or allowed to expand, it approximately follows Boyle's law. This law may be stated as follows: "The volume of a gas at constant temperature varies inversely as the absolute pressure to which the gas is subjected; or, what is the same thing, the product of the absolute pressure and the volume of a given quantity of gas remains constant."

Thus, if the volume is doubled, or one-half of the gas is removed from a fixed reservoir, the absolute pressure will be reduced one-half. Conversely, if the absolute rock pressure in a fixed reservoir is reduced to one-half, the volume of gas remaining compressed in that reservoir will be reduced to one-half.

It has been the universal custom of the natural gas industry to disregard the small deviation of natural gas from Boyle's law and in measuring computations to assume that the gas follows the law exactly. Tests made on the West Virginia gas indicate that the per cent of deviation increases with the pressure. That is, while there is no perceptible deviation at pressures under 15 pounds, at 150 pounds the deviation would be about 6 per cent. That is, the actual expansion of gas in lowering the pressure from 150 pounds down to less than 10 pounds would be about 6 per cent greater than that given by literal application of the law. This has the practical effect of making leakage in main lines and natural gas distributing plants sometimes seem considerably less than it actually is, due to failure to recognize that in expanding from high pressure to low the gas actually increases in volume more than the exact literal application of the law would give.[1]

EFFECT OF TEMPERATURE ON GAS VOLUME, KNOWN AS CHARLES' LAW.

"The volume of a given mass of any gas under constant pressure increases from the freezing point by a constant fraction of its volume at zero." This starts from the absolute zero of the gas, which is 492° F. below freezing, as shown at the right. In other words, the gas will expand 1/492 of its volume at 32° F. for each degree Fahrenheit rise of temperature.

This makes the change in volume directly proportional to the absolute temperature and means that approximately each 5° F. increase in temperatures makes an increase of 1 per cent in volume and each 5° F. decrease in temperature makes a decrease of 1 per cent in volume. For specific application of this see page 471.

GAS SAND OR GAS ROCK.

In no case is the gas found in rooms, caverns, or large crevices, as popularly supposed. "The oil and gas sands are simply very porous rocks which contain not only one great cavity, but millions upon millions of small or microscopic cavities, so that the oil, gas, water, or all three together, it may be, occupy these numerous little spaces, and thus saturate the rock just as water does a piece of cloth or a sponge when dipped into the same. The larger these pores are, and the greater the volume they occupy in proportion to the volume of the rock mass, the greater will be the contained oil or gas supply, and this proportion in fairly good producing sands, usually varies between one-fifth and one-tenth."[2]

DEFINITION OF ROCK PRESSURE.

When nature generated or deposited the natural gas in the rock reservoir—made up of the microscopic cavities between the sand grains—a fixed amount of gas was placed in a fixed inclosed space. The pressure in the rock—called "rock pressure"—was the result of the pressing into this fixed rock space of a larger volume of gas than the mere free air capacity of this rock reservoir. The degree of compression employed by nature in the formation process determined the intensity of the resulting pressure in the reservoir; that is, a high degree of compression produced a high rock pressure, and a low degree of compression produced a low rock pressure. Typical rock pressure decline curves are shown in figures 3 and 4.

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[1] Deviation of Natural Gas from Boyle's Law, by Robert F. Earhart and Samuel S. Wyer. Transactions American Society Mechanical Engineers, vol. 38, p. 285.

[2] I. C. White, West Virginia Geological Survey, vol. 1, p. 155.

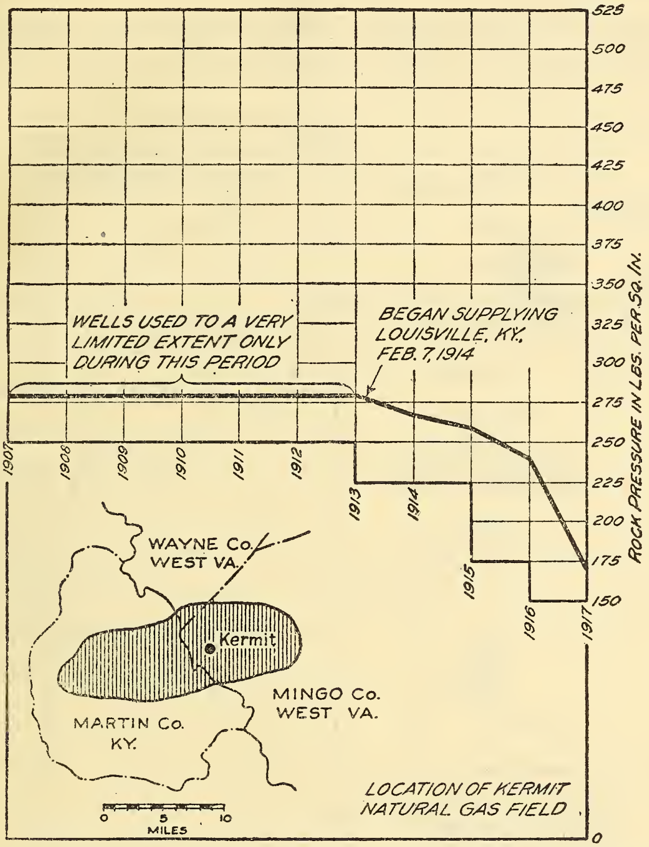

FIG. 3.—DECLINE IN ROCK PRESSURE OF NATURAL GAS WELLS OF THE UNITED FUEL GAS CO. IN KERMIT FIELD IN KENTUCKY AND WEST VIRGINIA.

WHY ROCK PRESSURE AND VOLUME MUST DECLINE.

The rock pressure and volume must decline as gas is removed, because in the removal of the deposit of gas we are confronted with the following:

1.—A fixed volume of the reservoir.

2.—A fixed amount of gas inclosed in this fixed reservoir.

3.—A certain rock pressure resulting from the contraction of the gas volume into the fixed reservoir.

Now, if a part of this fixed volume of gas is removed by tapping the reservoir from the surface of the earth, the remaining gas volume expands and keeps the reservoir completely filled, but at a lower pressure. Rock pressure decline is therefore inevitable whenever any gas is removed.

REGENERATION.

Food and trees can be grown. Water supplies are constantly replenished by nature, but there is no regeneration in natural gas; and when the gas is once used it is gone forever. While no one knows exactly how the natural gas is formed, yet enough facts are known about it to indicate that nature's process was a very slow one. It has taken millions of years to make the present concentrated supplies, and even though gas should now be formed in some parts of the earth's crust, the rate of formation will be so slow as to make such new gas pools of no interest or economic value for centuries, if ever.

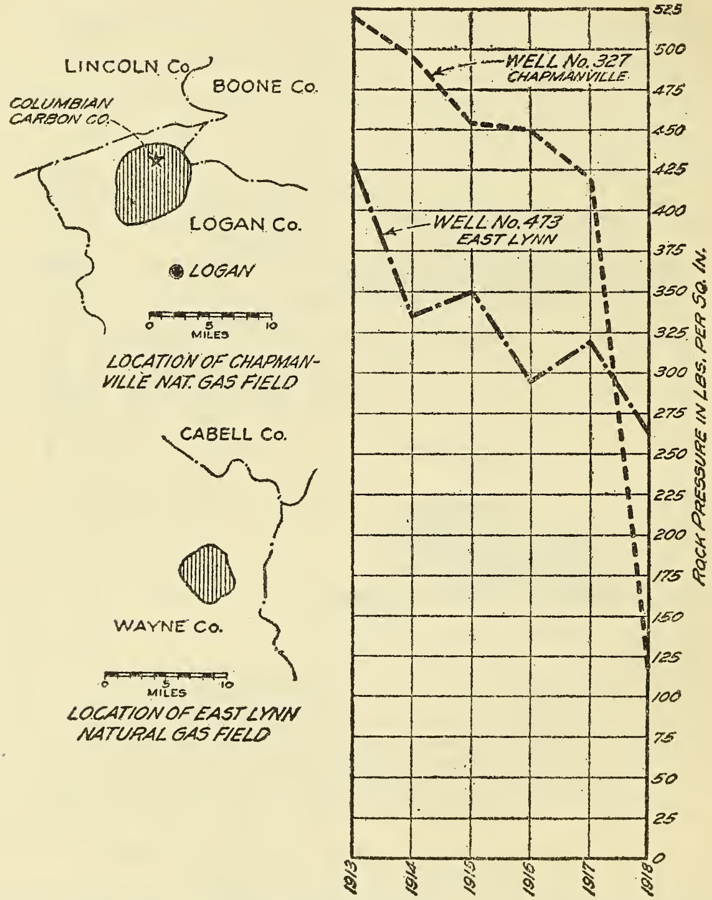

FIG. 4.—DECLINE IN ROCK PRESSURE OF NATURAL GAS WELLS OF THE UNITED FUEL GAS CO. IN EAST LYNN AND CHAPMANVILLE FIELDS, W. VA.

STORAGE OF NATURAL GAS.

Storage facilities for natural gas are not commercially feasible in the field nor at the delivering end of the transmission line, except the very limited use of existing gas holders in distributing plants. The large variation in service demands must therefore be met by the wells and reserve acreage. That is, the entire field operations must be subordinated to the peculiar service demands made on the natural gas company. An interesting contrast with these stringent operating conditions is the large storage equipment in acres of tank farms that may be used to equalize the load in the oil industry.

LIMITS OF GEOLOGY.

While earth structure is the essential element in the accumulation of large quantities of natural gas or oil, geological science is a directional indicator and hazard reducer only, and not a guarantor of commercial results.

Geology answers that by careful attention to her precepts, much of the waste that characterized the first three decades of the search for petroleum can be avoided, but that it is beyond her powers to foretell absolutely as to whether any particular boring will yield either oil or gas in commercial quantity. The careful geologist can eliminate many of the factors of uncertainty, and thus limit the search to regions having a peculiar geological structure where experience has shown that the occurrence of oil and gas is most probable, but further than this geology can not go, and no skillful geologist has ever claimed otherwise.[1]

LIMITS OF UNDERGROUND RESERVOIRS.

There is absolutely nothing fixed from the surface, and while surface conditions may be indicative, the question of underground location can be established by the drill alone. Even the presence of gas sand is not necessarily an indication of the presence of gas, as many dry holes show the full sand formation, without any gas in the sand. The dry holes shown in the map of the Triple State Field on plate 7 indicate a typical field situation, emphasizing the inability to determine underground limits except by drilling a hole.

OPEN OR NATURAL FLOW.

The courts have used the term "natural flow" synonomously for the engineering term "open flow," both, however, meaning exactly the same thing.

The term "natural flow" necessarily means the entire volume of gas that will issue from the mouth of a gas well when retarded only by the atmospheric pressure. (Appellate Court of Indiana, 66 N. E., p. 782. Richmond Natural Gas Co. *versus* Enterprise Natural Gas Co.)

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[1] I. C. White, West Virginia Geological Survey, vol. 1, p. 158.

The marked difference between the open flow of a gas well and the actual flow that may be obtained under routine operating conditions is emphasized in the next section.

MISLEADING WELL CAPACITY.

The natural gas well capacities that are given to the public are always the open flow capacity; that is, the capacity of the well in 24 hours when discharging freely into the atmosphere with no back pressure at all. This is misleading, and comes far from representing the true service capacity or true gas delivery capacity under routine operating conditions, of any gas well, because:

1. The first open flow measurements, which are usually the ones advertised in the newspapers, are nearly always made by the drillers, who do not have the facilities or skill to make an accurate test, and the errors are invariably on the side of a capacity larger than the actual facts. The volume is determined immediately after the well comes in, and is therefore larger than it would be several days afterward, on account of the fact that the well has not been drawn upon.
2. In routine operations of natural gas wells it is not possible to keep a well in service 24 hours, day in and day out. For various operating reasons, such as repairs, salt-water troubles, etc., it is necessary to rest wells at intervals. For this reason, the actual operating period of a well will be, on an average, very much less than 24 hours a day.
3. It is not feasible to maintain atmospheric pressure conditions in the pipes into which the wells discharge, but, on the contrary, the pressures are very much higher than atmospheric pressure. For this reason, the wells must discharge against considerable back pressure, thus retarding the amount of gas that will go out.
4. Based on actual operating tests, it has been determined that 25 per cent of the open flow capacity is about all that can be delivered from the average natural gas well. It must also be borne in mind that the open flow capacity will constantly decrease, with the removal of gas from the well.
5. As the rock pressure declines it will be necessary to install compressing stations in order to transmit the gas into and through the main transmission line.
6. After the compression station has been installed, the further inevitable decline in rock pressure will lower the capacity of such station, as shown on page 29.

MIGRATORY AND FUGITIVE NATURE OF NATURAL GAS.

Natural gas has no fixed position under any particular portion of the earth's surface. On account of its inherent tendency to expand it has the power, as it were, of self transmission and is capable of flowing from place to place in the underground reservoir, or of being drawn off by wells penetrating the natural reservoir at any point. Therefore, when one owner of the surface overlying the common reservoir exercises his right to remove natural gas, the supply in the reservoir will be decreased and the amount available to other owners of the surface in contiguous territory must inevitably diminish.

EXTENT OF NATURAL GAS UNDERGROUND DRAINAGE.

Gas is the most uncertain, fluctuating, volatile, and fugitive of all mining properties. It lies far below the surface, beyond the control of human will and beyond the reach of any legal process. On account of the characteristics just mentioned it is impossible to know at what distances drainage takes place. This depends on the unknown character of the sand and whether a well 500 feet or 1,000 feet distant would drain natural gas from an adjacent tract is largely a matter of conjecture and surmise.[1]

QUALITY AND QUANTITY OF NATURAL GAS FIXED BY NATURE.

The quantity is always uncertain and the quality may vary through a small range for the different fields. However, it is not commercially feasible to attempt to correct variation in quality by any artificial means and furnish a gas that is uniform, as may be done in an artificial gas plant, for the simple reason that the cost of doing this would be much more than the additional worth of the service under such conditions.

SCARCITY OF NATURAL GAS.

Natural gas is an exhaustible resource that when once used is gone forever. Every time a natural gas company sells 1,000 cubic feet of gas it is selling a part of its property. Furthermore, the number of natural gas consumers is increasing faster than the number of producing wells, thus placing an additional burden on each well, and the wells that are being drilled at the present time have a lower average capacity than wells that were drilled several years ago, in this way making less gas available.

The decline in average acres land held per natural gas well and average delivering capacity per natural gas well for the entire State of West Virginia is shown on page 22.

The decline in number of acres for a natural gas well of the United States Steel Corporation, operating under the name of the Carnegie Natural Gas Co., in West Virginia, is shown on page 23.

The decline in number of acres natural gas land for each well of the United Fuel Gas Co. is shown on page 24.

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[1] Paraphrased from Huggins *versus* Daley, 99 F. R., p. 606, and Hall *versus* South Penn Oil Co., 71 W. Va., p. 82.

For another operating company representing nearly 40 per cent of the State's production we have the following:

1. Number of acres natural gas land owned to a domestic consumer decreased from 3 acres in 1910 to 2 acres in 1917.

2. The average open flow capacity of new wells drilled declined from 1,200 M[1] in 1913 to 700 M in 1917.

3. The average annual production to a well declined from 3,600 M in 1910 to 2,200 M in 1917.

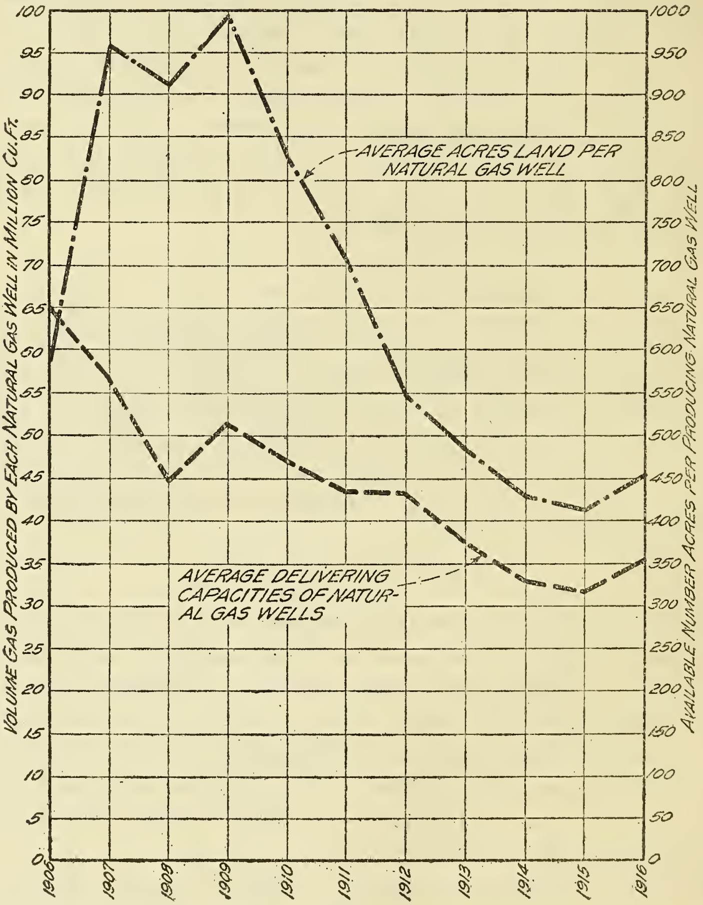

FIG. 5.—DECLINE IN WEST VIRGINIA NATURAL GAS RESOURCES, BASED ON DATA COMPILED BY THE UNITED STATES GEOLOGICAL SURVEY.

4. The number of domestic consumers that could be served by each producing well declined from 250 in 1910 to 170 in 1917.

5. Simultaneously with the above decline, the average annual gas service demands to the domestic consumer increased from 110 M

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[1] The letter "M" represents "1,000 cubic feet," the unit of gas measurement.

cubic feet each year in 1910 to 153 M cubic feet each year in 1917. The demands for West Virginia natural gas are emphasized elsewhere.

NATURAL GAS SERVICE IS BASED ON A NONCREATABLE AND NONREGENERATIVE MINERAL.

The natural gas business is unique in that it is the only public utility service that does not, and in fact can not, create the basis feature of the service that it renders to the public. Manufactured gas companies merely produce their gas from the raw fuel that they can buy in the open market; transportation agencies, like railroads or street railways, can easily create the motive source of their service; water utilities have their water supply constantly replenished by nature; intelligence transmission utilities, like the telephone and telegraph, can easily create the primary source of their service. However, the natural gas industry is alone in depending entirely on

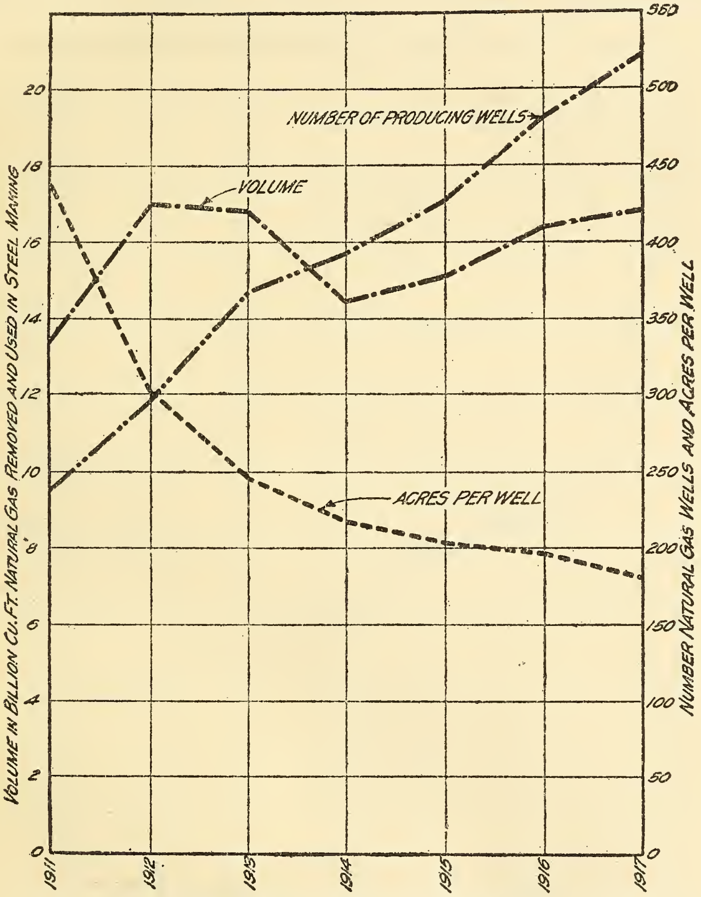

FIG. 6.—USE OF WEST VIRGINIA NATURAL GAS FOR STEEL MAKING, BY UNITED STATES STEEL CORPORATION.

the caprice of nature for first the finding, and secondly the continuity of the supply of its primary source of public utility service.

NATURAL GAS SERVICE AND OIL BUSINESS DISTINGUISHED.

Gas can not be gathered, stored, or transported in the same manner as oil. If found in sufficient quantity, it is turned from the well into the line and the pressure at the mouth of the well is the motive power by which it is driven through the line to the consumer miles away. If the pressure at a given well is much below that in the line with which it is connected, the gas from that well can not enter the line, but will be driven back by the superior force it encounters at the point of connection. For this reason, a well, producing gas in sufficient quantity to be profitably utilized, if there was a market for it near at hand, may be entirely valueless if its product must find a market at a distance too great to justify its transportation by a line of its own. In an oil district each well, no matter how large or how small its product may be, is separately operated, and a well may be profitably operated so long as its yield

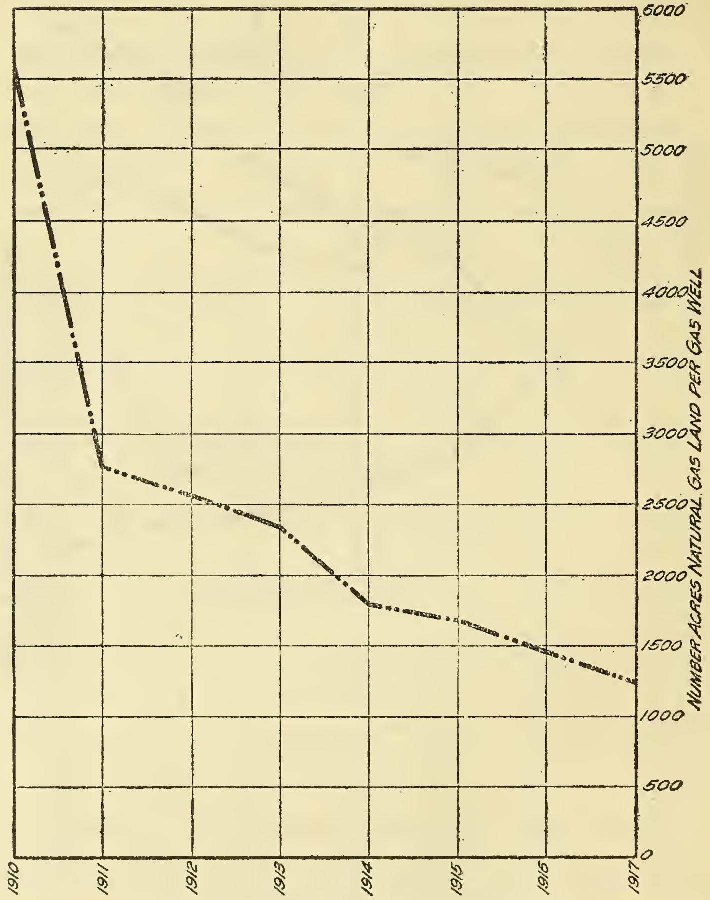

FIG. 7.—DECLINE IN NUMBER ACRES AVAILABLE NATURAL GAS LAND RESERVED FOR EACH NATURAL GAS WELL OF THE UNITED FUEL GAS CO.

pays more than the cost of producing the oil. In a gas district this is impracticable. The product of many wells is gathered into one line, so long as the pressure is sufficient. When the pressure in any one falls below the standard necessary for purposes of transportation, that well must be turned off. Its product can not be transported separately,[1] and unless it can be used near by, it is valueless. (Pennsylvania Supreme Court: McKnight *versus* Manufacturers Natural Gas Co., 146 Pa. St., p. 185.)

DRYING NATURAL GAS.

Natural gas as defined on page 10 is made up of a mechanical mixture of condensible vapors and permanent gases; the condensible constituents consist of gasoline vapor and water vapor. In the transmission of the gas, due to changing temperature and pressure

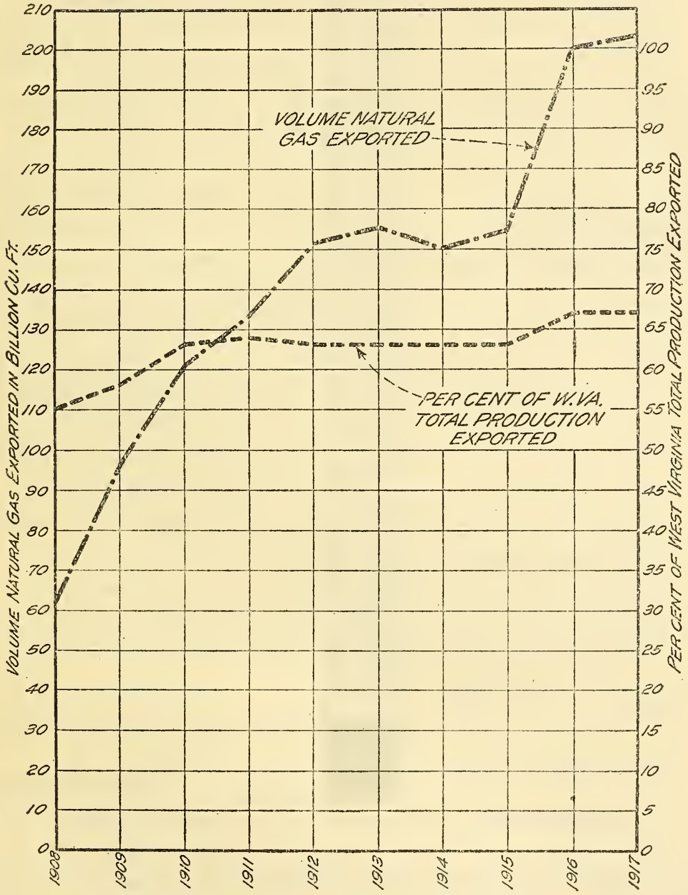

FIG. 8.—NATURAL GAS EXPORTED FROM WEST VIRGINIA.

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[1] Gas compressors can, of course, be installed so as to increase the pressure of the gas to permit its delivery into a line. The operating cost of this, however, may be much more than the market value of the gas. This, of course, is a very pointed illustration of the fundamental fact that in order to make gas conservation possible it must be made worth saving.

conditions, part of these vapors are condensed and then precipitated in the form of a liquid, and will give trouble in choking up the line, and the water may freeze, closing the line entirely.

The gasoline will soften and decompose the rubbers in the couplers. This is due to the solvent action of the gasoline on the rubber, and the immediate effect will be to cause the joints to leak, thereby greatly increasing the leakage loss.

The general tendency of natural gas is to become wetter as the well becomes older, and, therefore, natural gas from a new well that may be so dry as not to yield any gasoline at all, may yield gasoline in commercial quantities after the well has been in use for several years. The removal of the gasoline and water vapor carried by natural gas is desirable from the consumers' viewpoint for the following reasons:

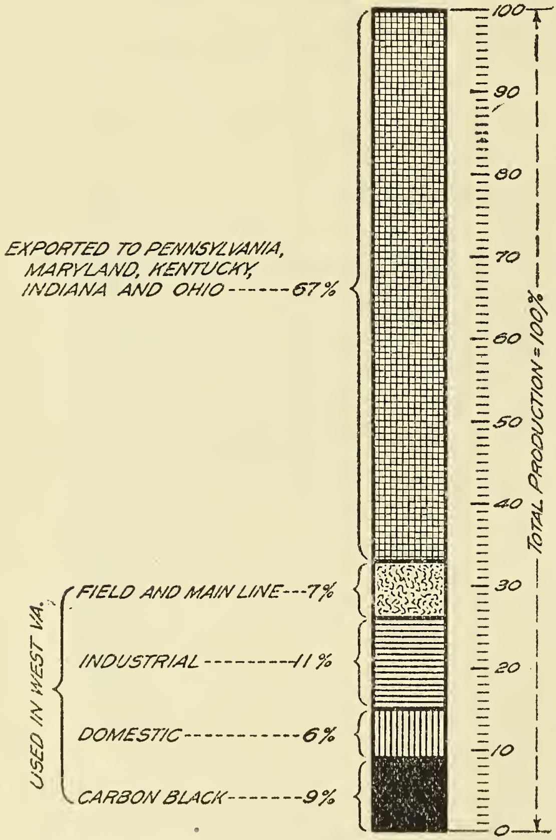

FIG. 9.—USES OF WEST VIRGINIA NATURAL GAS IN 1917.

1. Heating value is little disturbed, the removal of the gasoline from dry natural gas lowering the heating value only about 2 per cent.

2. Gasoline vapor exists in such a form that practically none of it ever can be delivered to the ultimate consumer.

3. The condensed gasoline vapors will injure the rubber in the couplers and in this way increase the leakage of the transmission line.

4. The condensed water vapor will freeze, causing interruption of service, or disturbed and fluctuating pressure conditions.

5. The removal of water and gasoline by blowing the drips results in a large waste of natural gas.

6. The drying of the gas tends to stabilize the gas service by decreasing line troubles.

Similar conclusions have been presented by the United States Geological Survey, on pages 645 and 646, in Natural Gas Statistics for 1916, and in Bulletin No. 120, page 11, of the United States Bureau of Mines.

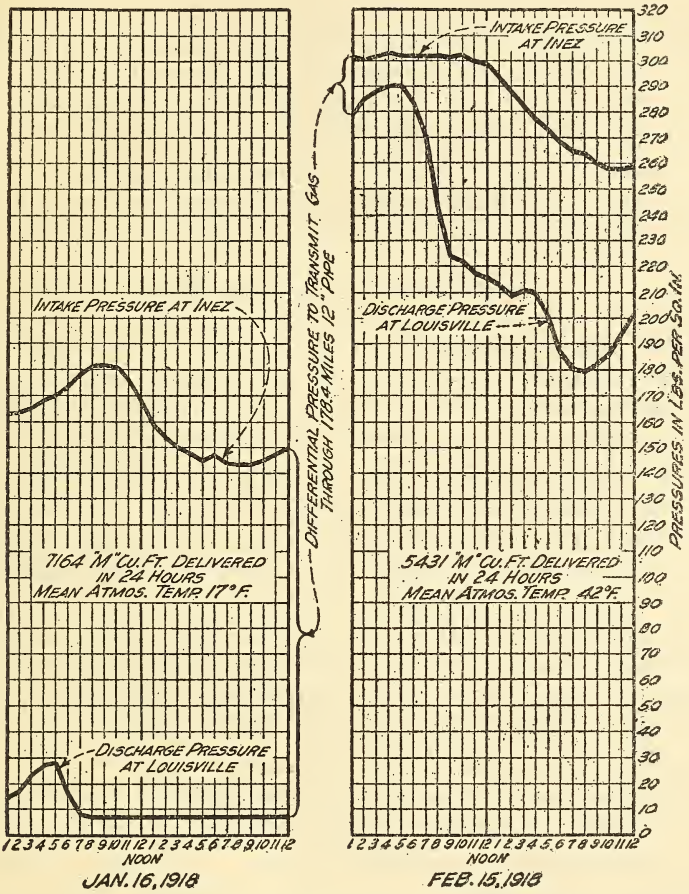

FIG. 10.—TYPICAL NATURAL GAS TRANSMISSION LINE PRESSURE CONDITIONS.

PRINCIPLES OF NATURAL GAS TRANSMISSION.

TRANSMISSION IS MORE THAN MERE TRANSPORTATION.

Continuity of service from the gas sand—usually one-half mile or more below the earth's surface—through the gas main as a continuous conduit connecting the gas sand and the consumer's fixtures, many miles away, is a cardinal feature of the delivery of natural gas. The general custom of the natural gas business has been to refer to the taking of natural gas from the gas sand to the consumer as transportation. However, the word transmission more correctly expresses the actual operation.

Transmission from the roots, *trans*=across, and *mitto*=to send, emphasizes the fundamental ideas of "to send through" and "to send" and where interstate lines are involved, to "send across" such lines. The fundamental idea "to send" is especially relevant, because the gas is always sent through the line by virtue of its own expansive force, as explained on page 101, and never pulled through by anything ahead, while transportation from the roots, *trans*=across, and *porto*=to carry, suggests fundamentally transference only. That is, you transmit through, but transport over. Transmit, for "to send," fixes the attention immediately on the intervening agency and relates to the service, while transport relates to the commodity, although both imply delivery.

WHY NATURAL GAS IS COMPRESSED.

Natural gas is compressed merely to expedite transmission—for the same reason that makes it necessary to compress cotton, hay, or straw, for shipment. The first feature is to contract the volume, and secondly, to secure enough pressure range between the intake and discharge of the transmission line to secure a large enough pressure drop to force the gas through the line.

The broad public interest in an effective and continuous service and a future generation's equity in a conserved future supply makes it the duty of the gas-producing company:

1. To conserve the supply of gas in every way possible. By conservation is meant not merely saving, but using in the most effective manner. This means that it is the duty of the gas company—when it can be done without financial loss—to remove every foot of gas from the ground that can be obtained.

2. Every appliance known to the art ought to be used to bring about the most economical mining of the gas, and most effective method of transmission and distribution. A normal characteristic of every gas field is that its rock pressure declines each year as the gas is removed from the ground, as shown in graphical form in figures 3 and 4. This means that as the fields grow older it is necessary for the gas company to increase the rapidly declining pressure by mechanical means.

HOW NATURAL GAS IS COMPRESSED.

This is accomplished by a compressor which is merely a mechanical device to squeeze the gas together into a small volume, thereby increasing its pressure. The specific effect of gas compression is evident from the following: If we take 1,000 cubic feet of gas at 4 ounces gage pressure and increase the gage pressure to 300 pounds, the volume will be contracted to 46 cubic feet.

STATUS OF GAS COMPRESSOR ART.

The art of natural gas compression is now over 29 years old and has grown at practically the same rate as the increase in domestic natural gas consumers. There are now over 220 natural gas compressor stations in North America, aggregating approximately 350,000 horse power of compressor capacity and compressing about 90 per cent of all the natural gas used. The age and magnitude of the art make it evident that the use of gas compressors is a recognized integral part and universal custom of the natural gas business.

"GAS COMPRESSING" AND "GAS PUMPING."

These terms, unfortunately, are almost universally used synonymously to describe the contraction of volume of gas by compressing it with a machine known as a gas compressor.

Much misunderstanding has arisen because the term pumping station has come into general use in speaking of gas compressor stations. This is wrong, for the reason that the term pumping signifies the action of lifting alone, or lifting combined with force. In the case of natural gas transmission the work is one of pure compression, since the gas is delivered to the gas compressors under an initial pressure considerably higher than the atmospheric pressure, on account of the natural rock pressure forcing the gas out from the wells into and through the intake lines to the compressors.

ROCK PRESSURE DECLINE LOWERS COMPRESSOR CAPACITY.

As the rock pressures of the gas wells decline, the pressures that have been maintained on the intake side of the gas compressors are also lowered. This has the immediate effect of lowering the capacity of the compressing station.

The output of a typical compressor operating against a discharge pressure of 300 pounds gage is as follows, for the respective intake pressures:

Intake pressure above atmosphere.	Capacity in million cubic feet free gas each 24 hours, based on 14.4 pounds atmospheric pressure.
150 pounds	30
100 pounds	20
75 pounds	15
50 pounds	10
30 pounds	6
20 pounds	4

SIZE AND COST OF LINES NECESSARY WITHOUT COMPRESSORS.

From an engineering viewpoint it would be possible to take the gas to market without compressors, by simply building a great number of large size lines. However, the number and cost of lines necessary to do this would be so great as to make the plan prohibitive from a financial viewpoint. That is, the gas compression method is the economical way of handling the problem. The natural gas compressor performs a similar function to the step-up transformer for an electrical transmission line.

NO HEAT LOSS IN NATURAL GAS COMPRESSION.

Contrary to a widespread popular opinion, the compression of natural gas does not decrease its heating value. While a certain amount of gas is used to drive the compressors, this does not in any way affect the heating value of the gas passing through the compressors. On account of the mechanical work performed on the gas as it flows through the compressors the gas becomes quite warm, and to protect the rubbers in the main lines, is cooled just beyond the compressor discharge before it goes into the main line transmission system. This, however, pertains merely to the temperature of the gas itself, and in no way affects its heating value.

NOT FEASIBLE TO MAKE NATURAL GAS MAIN LINES COMMON CARRIERS.

The natural gas main lines form the connecting link between the mining operations in the natural gas field and the public utility service in the city distributing plants. A number of attempts have been made by large consumers, owning natural gas in the field, to have the main transmission lines made common carriers so that they could be compelled to haul the large consumer's gas to market. The converting of main lines into common carriers is not only not feasible from an operating viewpoint, but the idea could be based only on distinctly local and selfish interests, and would ignore entirely the domestic consumers' interest. That is, this plan would greatly injure service to the over 2,000,000 domestic natural gas consumers in the United States, because it is not generally appreciated that:

1. There is a clear distinction between the duties of a common carrier or railroad, and the duties of a public utility.

(*a*) The terms "railroad," "common carrier," and "public utility" are frequently confused. A railroad is a common carrier that undertakes for hire to transport persons or goods, or both, from place to place, for all persons indifferently. The fundamental duty of a railroad or common carrier being indifference as to who shall be served, and an equal readiness to serve all who apply in the order of their application. On the other hand a property becomes a public utility only when dedicated to a public use.

(*b*) Even though legislative enactments would be passed declaring natural gas lines public transportation agencies—that is, common carriers—they could not be enforced because such legislation would be in direct conflict with well-known economic and engineering facts. The entire natural gas transportation problem is controlled by economic and engineering laws. These laws can neither be abrogated nor altered by company policy, contractual relations, public opinion, legislative enactment, or judicial decree. They are entirely independent of human opinion, and as certain in their operations as the law of gravitation. Therefore, no mere statement of any governing body can make a public transportation agency of a natural gas line.

(*c*) The fundamental requirement of a common carrier agency like a railroad is nondiscrimination, and this can in no way be applied to the duties of a natural gas company. A natural gas company operating a natural gas transmission line and supplying domestic consumers, from the very nature of things, gives its own consumers preference on account of public policy and the contractual relations existing between such consumers and the gas company.

2. The consumers' interests and rights extend clear back to and depend on the gas wells and reserve acreage the producing company maintains to insure an adequate present and continuous future service. Common carrier obligations for the transmission line would:

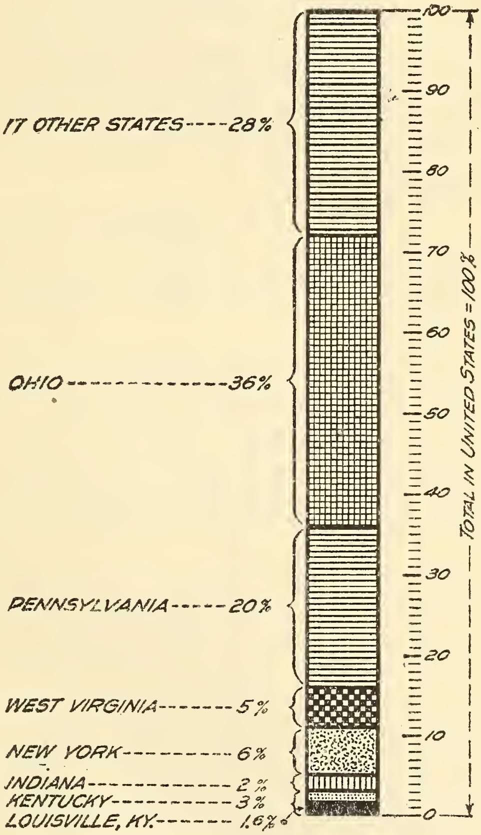

FIG. 11.—GEOGRAPHICAL DISTRIBUTION OF DOMESTIC NATURAL GAS CONSUMERS BY STATES.

(*a*) Tend to soon exhaust the available supply and leave the householders with large investments of appliances and pipes which will be useless, owing to the permanent failure of gas.

(*b*) So disorganize the existing business as to make it impossible to render satisfactory continuous service to either domestic or industrial consumers. This would be true regardless of what might be charged.

(*c*) Make the consumers—especially the domestic—subordinate to occasional producers; that is, to men who have no intention of following the business of hunting for gas for future service, but would be interested only in finding a good market, at the expense of others, for such gas as might be found as a result of an occasional accidental venture.

(*d*) In all cases, where tried, impair and usually destroy the cooking, heating, and lighting service of the domestic consumer.

(*e*) Greatly increase the amount of gas used for manufacturing purposes, thus hastening the day when natural gas will be merely the memory of a wasted and unappreciated resource.

3. The attempt to convert natural gas transmission lines into mere common carrier transportation agencies, like railroads, presents many features that are impossible and none that are feasible or expedient, because:

(*a*) Natural gas companies in general are not chartered to act, and do not offer to act merely as transportation agencies.

(*b*) Natural gas service to the public is so unlike the service rendered the public by railroads that no comparison can be made between them.

(*c*) The distinction between handling a commodity and rendering a service is an important one, as explained on page 34.

(*d*) Even though natural gas is a mineral it requires constant attention from the time it is reduced to possession at the well, and embodies an unbroken chain of service features until it is burned at the consumer's fixtures. A railroad may operate its line in many small units, rendering service to many different localities and to many different people with unrelated, isolated service units.

(*e*) Natural gas service must be instantaneous. There can be no delays in rendering service, as is possible (and universally practiced) in transportation agencies such as railroads and traction lines. For instance, a railroad can very easily start service one hour late in case of congested traffic, but a natural gas service that delivers gas for cooking breakfast one hour after the consumer needed it would not only be valueless to the consumer, but would not be tolerated in any community. This instantaneous feature differentiates natural gas service from all transportation agencies.

(*f*) The gas is never at rest, but is a constantly seething, moving mass between the gas in the field and the consumers' fixtures in the cities. The gas travels at enormous velocities in the mains at a speed many times exceeding that of the fastest trains.

(*g*) The gas can go in only one direction.

(*h*) Storage facilities are not feasible for the gas either in the field or in transit.

(*i*) The gas pressures must be varied to suit the operating conditions of the line; that is, at the intake of the line the pressure must be large and at the discharge end of the line the pressure must be relatively low as shown on page 27.

(*j*) There is no delivery until the gas has not only passed through the consumer's meter, but is burned at the consumer's fixtures.

(*k*) In considering the gas that goes through the line there can be no "identity of property," no "segregation of ownership," and no "original package containers," but all of the gas obtained from various sources passes through the line thoroughly intermixed with absolutely no possibility for identification.

(*l*) The capacity of the transmission lines is rigidly fixed and will not stand any overload. This has a marked effect in taking care of peak loads, in contradistinction to railroads, which may run extra trains to carry extra traffic.

(*m*) A natural gas line can handle only one commodity, whereas railroads can handle every known commodity.

(*n*) Railroads have vehicles of transportation. Natural gas lines have none. The pipe line is merely a continuous conduit between the field and the consumer's fixtures.

(*o*) A natural gas line can not have extensive interconnecting service with other lines, whereas every railroad can handle commodities from every other railroad.

(*p*) The transmission of natural gas is naturally centralized relatively near the fields of production, the deliveries being made near the fields, and not throughout the whole United States, as are commodities handled by railroads.

(*q*) The domestic gas consumers will not contract for, or agree to use, a fixed amount of gas each day, but take gas as they need it, in all cases insisting and requiring that the service be made and maintained continuous.

(*r*) The company can not create the commodity upon which it is performing its service as is possible with manufactured gas, electricity, or any of the transportation agencies; neither is there the constant replacement by nature of the commodity it is serving, as is the case in waterworks plants.

(*s*) The system must be operated as one unit, without regard to state lines.

4. Gas companies discharging their legal duty to their domestic consumers can not depend upon the initiative of the occasional producer for a supply of gas, but must depend upon their own initiative in order to maintain proper field operating conditions and an adequate reserve acreage for future development to insure a good serv-

ice to their patrons. In West Virginia the total production is delivered as follows:

	Per cent.
Utilities	82
Small producers, with no public utility duties	13
Carbon black manufacturers	5
	100

Experience has many times shown that satisfactory continuous service to the consumer can be rendered only when the production, transmission, and distributing features are properly coordinated. To subordinate the transmission side of the business to either the producer's or the larger industrial consumer's interest is indefensible.

NATURAL GAS DISTRIBUTION.

NATURAL GAS IS A SERVICE, NOT A COMMODITY.

The furnishing of a service, rather than the delivering of a commodity or product, is the dominating feature of the natural gas business. To consider the gas merely as a commodity is fundamentally wrong. When a natural gas utility prospects for, finds, and reduces the fugitive, wandering and uncontrolled natural gas to possession, and then converts this crude natural gas—made up of a mechanical mixture of permanent gases and condensible vapors—into a controlled and usable service delivered to the consumer's fixtures, usually many miles from the gas field, the service features pertaining to the method and manner of delivery, and standing ready to serve are of much more importance than the product or commodity.

The difference between rendering a service and marketing a commodity is an important one. The commodity may be manufactured at a uniform rate of production and then placed in storage until it can be sold to advantage, while a service must be used at the moment it is offered or it will become forever useless. The load factor data on page 35 emphasized, first, the erratic nature of natural gas loads and, secondly, the potential opportunities for rendering service that can never be used.

WHY GAS CONSUMERS USE MORE NATURAL GAS THAN MANUFACTURED GAS.

The average consumption in M cubic feet of natural gas for all the domestic natural gas consumers in the United States is 100 M cubic feet by each domestic consumer annually. The consumption data for Charleston, Huntington, and Louisville, Kentucky, is shown in graphical form on pages 35 and 36.

The average of 682 manufactured gas companies, as reported in Brown's Gas Directory, was 22 M cubic feet of manufactured gas to each domestic consumer a year. The actual average annual consumption of manufactured gas at Louisville, Kentucky, prior to the introduction of natural gas was 24 M cubic feet.

The reasons for this large increase in domestic natural gas consumption are as follows:

1. Natural gas prices have been so low as not to make the gas worth saving.

2. The efficiencies of most natural gas using appliances are generally less than for manufactured gas using appliances. See page 40.

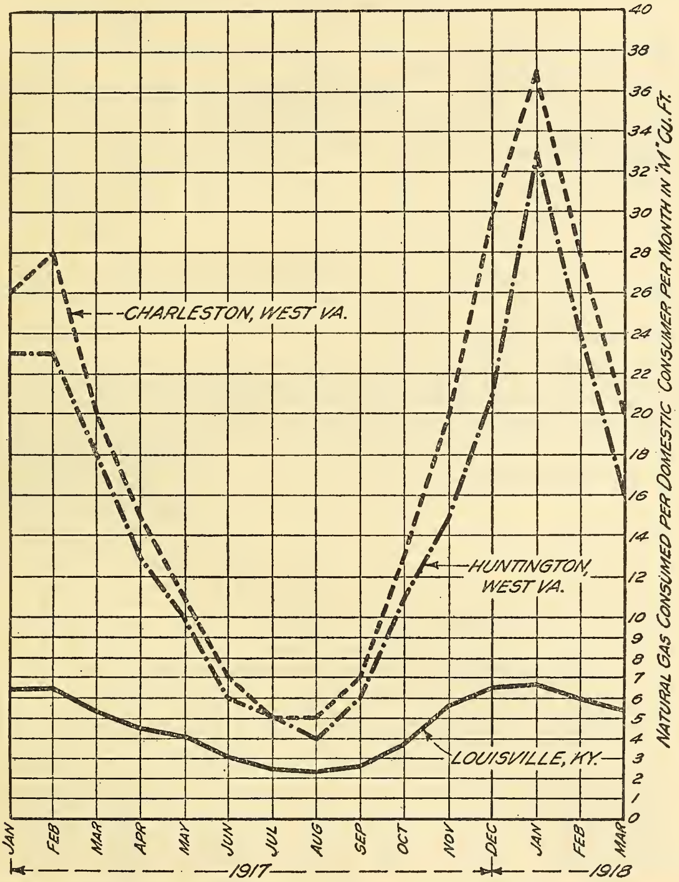

FIG. 12.—MONTHLY AVERAGE NATURAL GAS CONSUMPTION PER DOMESTIC CONSUMER.

3. Manufactured gas is used primarily for cooking, hot water heating, and lighting only. The largest part of the natural gas business results from its extensive use for house-heating services, where the volume required is very much greater.

PEAK LOAD SERVICE.

Abnormal peaks of very short duration are characteristic of all natural gas loads for domestic consumers. This necessitates a large property value for equipment that is actually used only a very short period out of each year. Every natural gas company must have considerable equipment that will be used not over four hours daily during say 30 of the coldest days of a year of normal temperature. The smallness of this is evident from the following:

Total number hours in the year________ 24 × 365 = 8,760 = 100 per cent.
Hours peak load equipment is actually used ________________________________ 4 × 30 = 120 = 1.4 per cent.

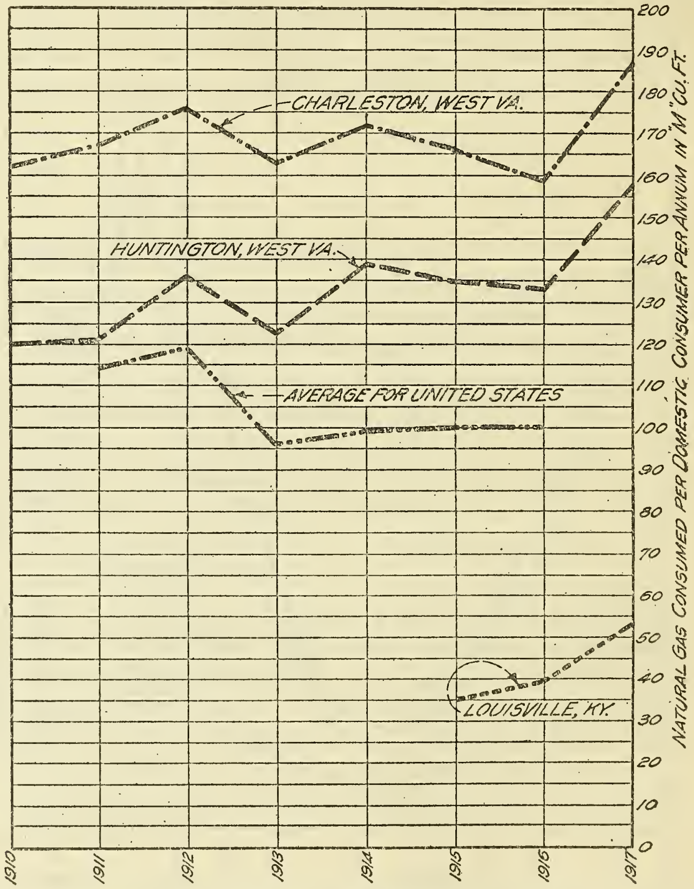

FIG. 13.—ANNUAL AVERAGE NATURAL GAS CONSUMPTION PER DOMESTIC CONSUMER.

Industrial loads ordinarily are very much more uniform than domestic loads. This is especially true of the carbon black industry in the field, where the load can be made uniform every day of the year. The relationship between maximum, minimum, and average load conditions is shown on page 37.

PEAK LOADS INCREASE COST OF SERVICE.

An increase of volume of business can decrease the cost of production only when the increment of increase is distributed so as to make possible the more efficient use of existing equipment. When the increment of increase is concentrated so as to require more equipment, as is the case in all peak loads, the cost of production to the unit of service is increased. Therefore, the cost of peak load natural gas service is greater than the cost of normal service. A rate schedule, to be equitable to all consumers of natural gas, must make the consumers who need and create the peak load service, pay a price that will be commensurate with the extra cost of the service they are receiving.

House heating furnace services not only produce marked peaks each day, but the consumption is limited to relatively a short period out of each year. For this reason house heating furnace service costs more than ordinary gas service. This emphasizes the desirability of the use of auxiliary heating equipment, as outlined on page 38.

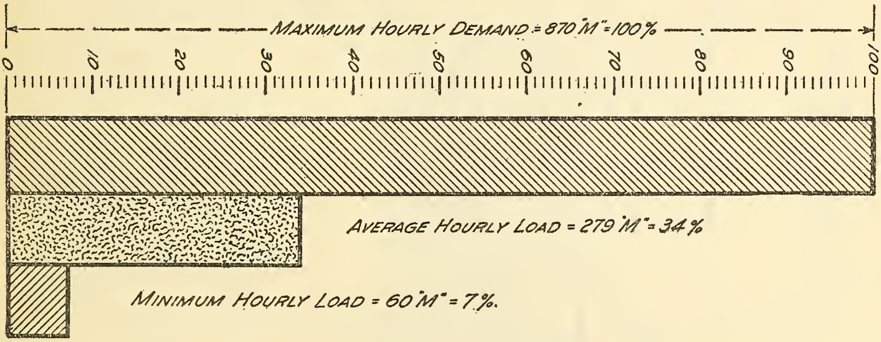

FIG. 14.—RELATION OF MAXIMUM, AVERAGE, AND MINIMUM HOURLY NATURAL GAS LOADS.

BASIC REASONS FOR LARGE SALES OF INDUSTRIAL GAS.

These have been inadequate domestic price and policy of Government in fostering competition in the gas field.

During the domestic off-peak period—usually nine months of the year—about 60 per cent of the equipment of a gas company is not needed for domestic natural gas service. Under competitive conditions in the field the gas can not be conserved for future use, except by unity of action of all producing companies. As the Government has always fostered competition, and therefore waste, the inevitable result has been to stimulate low-priced industrial gas sales, because:

1. The companies needed the revenue to make up the deficit from their too low priced domestic gas service.

2. As no one company could save its gas, except by the prohibitive "unity of action of all producers," each took all the gas it could get, as fast as it could get it out, thereby greatly depleting the supply for future service.

At the present time of all the gas produced in the United States, practically two-thirds is used in industrial service. The percentage of total State consumption that is used for industrial service, for several States, is shown on page 39.

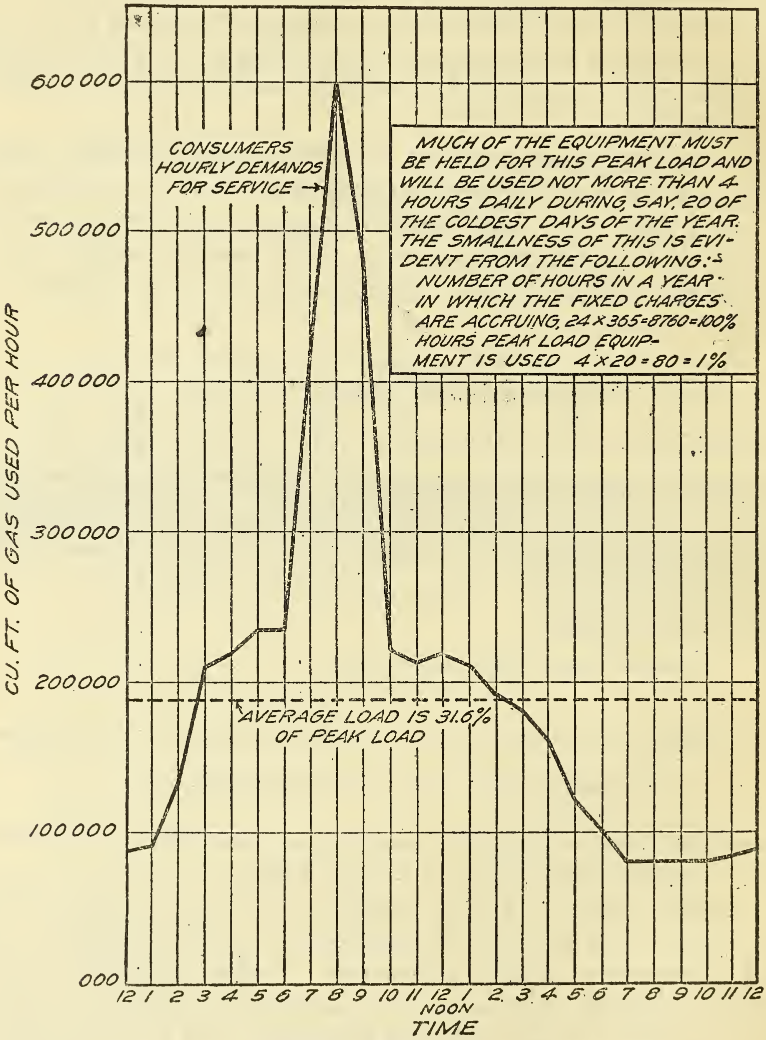

FIG. 15.—TYPICAL HOURLY NATURAL GAS LOAD IN WINTER.

The pooling operating conditions referred to on pages 62 and 63 would greatly curtail this misuse of gas for industrial purposes.

PEAK LOAD CONDITIONS ANALOGOUS TO STRAP HANGER PROBLEM.

While it would be possible for a street car company to install and operate enough cars during the peak-load period to give everyone a seat, yet the cost of so doing would make the general service cost much more than the additional advantages would be worth. Since the demand for seats may be four or five times as great during the rush hours as it is in the middle of the day, the only feasible way to deal with this situation is to admit the necessity of a different standard of service for rush and nonrush periods. Since the fare remains constant, it becomes necessary to provide relatively fewer cars, and therefore fewer available seats, for the rush period than for the nonrush travel.

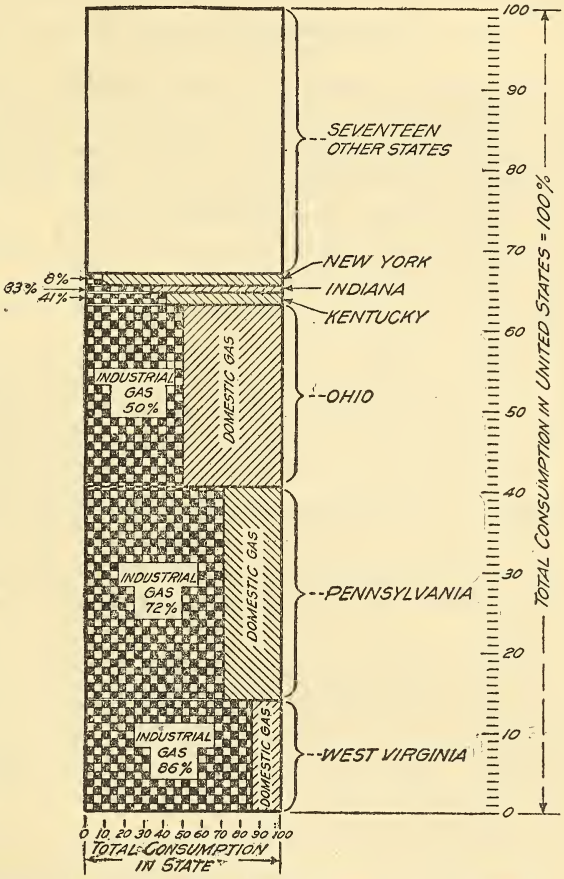

FIG. 16.—RELATION OF INDUSTRIAL AND DOMESTIC NATURAL GAS CONSUMPTION.

But for the uniformity of street railway rates, the rush hour passenger might justifiably be charged more than the nonrush passenger. Conversely, it is not unreasonable that he should, paying the same fare, expect to have to put up with a somewhat less comfortable ride at that time. There is certainly little economic ground for an especially reduced fare for this service.[1]

This is precisely the situation with regard to natural gas pressures during the peak load period, with this further feature, that the natural gas peak load periods cover relatively only a few days of the year, as against the everyday situation on street car traffic. As long as natural gas prices for the higher costing peak load service remain the same, the consumer must therefore expect a lower standard of service during that period.

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[1] Quarterly Journal of Economics, August, 1911, p. 623.

USE OF AUXILIARY HEATING APPLIANCES.

It is desirable in all cases where possible to have auxiliary heating equipment available for supplementing or entirely replacing for a short period natural gas for house-heating service, during the peak period of the load. Where gas furnaces are used, auxiliary oil burners can be installed in such fire pots, or auxiliary coal furnaces can be installed alongside the gas furnaces, where the coal furnace would discharge its heated air into the gas furnace shell.

FEW IMPROVEMENTS IN ART OF USING NATURAL GAS.

On account of the low prices that have prevailed, gas-appliance manufacturers have not been stimulated to the development of efficient gas-using equipment. There have been few improvements resulting in increased efficiency in the last 15 years. In testing house-heating furnaces it has been found that:

1. The use of natural gas in the fire pot of a coal furnace gives an efficiency of about 25 per cent.
2. The use of natural gas in the ordinary gas furnace gives an efficiency of about 35 per cent.
3. The use of natural gas in a correctly designed and built gas furnace, where the construction conditions permit the fullest utilization of the heat in the gas, gives an efficiency of about 75 per cent.

In tests made by the Bureau of Standards, it was found that the ordinary incandescent mantle lamp where used with natural gas wasted nearly half of the possible heat that could be used if such lamps were designed for as efficient operation on the high heating value natural gas as they give on the low heating value manufactured gas.

In tests made by the department of home economics, Ohio State University, the efficiencies of a natural gas range varied from 37 per cent with 0.2 of an ounce pressure down to 13 per cent at 4-ounce pressure,[1] while with a manufactured gas range, using natural gas, the efficiencies varied from 43 per cent at 0.2 ounce pressure to 23 per cent at one-ounce pressure.

COOKING AND HEATING DISTINGUISHED.

In a heating operation it is merely necessary to secure perfect combustion in the heating device, because in so doing all of the available heat in the gas can be utilized. In cooking it is not only desirable to secure a perfect combustion, but absolutely necessary to direct the heat to a particular place, in a particular manner, and sometimes at a particular time. It is for this reason that gas-cooking operations are more susceptible to changed pressure conditions than heating operations.

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[1] Ohio State University Bulletin, vol. 22, No. 28, May, 1918: Effect of Gas Pressure on Natural Gas Cooking Operations in the Home.

It may not be amiss to emphasize that the time element in many cooking operations is of much more importance than intensity.

WHAT IS USABLE NATURAL GAS PRESSURE.

The pressures carried by most natural gas companies have been too high for efficient service. This has had the further undesirable feature of teaching the consumer to believe that he was not receiving service unless the gas could be heard hissing through the orifice in the gas mixer. It has been demonstrated that[1]—

1. Satisfactory cooking operations in frying potatoes, boiling potatoes, frying beefsteak, and pan-broiling beefsteak can be carried on with 0.2 ounce natural gas pressure. This merely requires that the short flame and cooking vessel be brought together. The changes in vessel position necessary to permit satisfactory operation at pressures as low as 0.2 ounce are easy to make, require no special changes in existing stoves, and consist merely, with drilled burners, in placing three nails in three of the drilled holes, and, with slotted burners, of placing three small pieces of tin in three of the slots, in order to support the cooking vessel at the proper distance from the burner, and close enough so that the short flame can do effective work.
2. Better results are obtained with pressures in the neighborhood of 2 ounces than at 4 ounces.
3. Less gas is used at pressures in the neighborhood of 2 ounces than at 4 or 5 ounces.
4. Manufactured gas range gives better results than natural gas range because the former is designed for low pressures.
5. There is very little difference in the time required to carry on cooking operations with pressures of from 1 to 5 ounces.

Therefore, if the consumer will use proper appliances, satisfactory cooking operations can be carried on with pressures as low as 0.2 ounce and the gas passing through the meter will perform a usable service.

With heating appliances, if the mixer is properly adjusted the combustion at low pressures can be made substantially as thorough as at high pressures, and the consumer can have the benefit of all the heat generated by the burning gas, although if the pressure is low he will invariably not have nearly as much as he would like to have or as he needs. However, all of the gas measured by the meter and burned in the heating appliance is used for a useful service, so far as it goes, although under extreme low pressure conditions there is not enough to give all consumers all they want.

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[1] Ohio State University Bulletin, vol. 22, No. 28, May, 1918: Effect of Gas Pressure on Natural Gas Cooking Operations in the Home.

ACCURACY OF METER REGISTRATION AT LOW AND VARIOUS GAS PRESSURES.

The popular belief is that meters run faster when the pressure is low than when the pressure is high. This is contrary to the facts. Variation in pressure makes no appreciable difference in the registration of the meter, the meter merely registering, within a reasonable limit of tolerance, the amount of gas that passes, and this is neither increased nor decreased by changes in pressure.[1]

EFFECT OF GAS PRESSURE ON GAS LEAKAGE.

A summary of gas leakage laws is given on page 58. From these it will be seen that the leakage at 4-ounce pressure is twice as great as at 1-ounce. For this reason the leakage in the city distributing plant and on the consumer's premises, which is paid for by the consumer because the gas must pass through the consumer's meter in order to leak away on his premises, will be substantially less if the distributing plant and consumer's fixtures are adjusted for low pressures rather than high pressures.

GAS METER FACTS.

The following features regarding gas meters should be borne in mind:

1. Gas meters have no power within themselves to register. The only way they can be made to register is by the passage of gas through the meter. The gas company has absolutely nothing to do with the operation, nor can it in any way control the registration of the meter. However, many times gas meters register when gas is not being used, due to leakage in house fixtures.
2. The gas consumption will not be increased by the use of a large meter.
3. The gas consumption will not be decreased by the use of a small meter. In fact, if the meter is too small the gas service will be unsatisfactory.
4. Gas bills are not made out regardless of gas consumption. While it is possible for the meter reader to make an error for one month, this will be automatically rectified in the reading of the following month.
5. High gas pressure does not increase or decrease the rate of registration of meter.

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[1] The same conclusion was reached in: Engineering Bulletin No. 2 of the University of Kansas, on Natural Gas: Its Properties, Its Domestic Use, and Its Measurement by Meters, under date of July 1, 1912. Paper on Value of Gas Delivered at Varying Pressures, by Charles V. Critchfield, of the Ohio Public Utilities Commission, read at the Pittsburgh meeting of the Natural Gas Association of America, May, 1918. Ohio State University Bulletin, vol. 22, No. 28, May, 1918: Effect of Gas Pressure on Natural Gas Cooking Operations in the Home.

6. Low gas pressure does not increase or decrease the rate of registration of the gas meter.

7. It is impossible for a gas meter to register twice. When the gas has passed through the meter it can not pass through the second time.

8. Meters do not always register fast. There are just as many times when they register slow, and this is to the detriment of the gas company.

DISTINCTION BETWEEN LUXURY AND NECESSITY IN NATURAL GAS SERVICE.

To the average family for cooking, hot water boiler heating, lighting, and incidental house heating service, natural gas is a necessity, but when used in larger quantities or for house-heating furnace work it becomes a luxury. Furthermore, the peak load characteristics of house heating furnace service make this service cost more to the natural gas company. An equitable schedule of rates ought, therefore, to provide for a fixed net price per thousand cubic feet for a large enough monthly consumption to permit of the cooking, hot water boiler heating, lighting, and incidental house heating service necessary in the average family. If this fixed consumption is exceeded, then the price of a thousand cubic feet for such excess consumption ought to be increased so as to make the consumer pay for the higher priced service he is receiving.

It is a trite observation that the luxuries of one day tend to become the necessities of the next. Most complaints for inadequate service during the few peak load hours, usually less than 1 per cent of the total 8,760 hours in the year,[1] are based on the fallacy that a service that is purely a privilege has become a prerogative; that is, natural gas consumers as compared with other fuel users who have to use solid fuel or manufactured gas are a privileged class enjoying a luxury that is seldom appreciated until it becomes difficult to obtain, and on account of the limitations fixed by nature they do not possess and can not ask any inalienable rights of service, under conditions that are physically impossible to meet.

CONSUMER IS RESPONSIBLE FOR ECONOMIC USE OF GAS.

The consumer's use of gas has an important bearing on the efficiency of results that may be obtained, as discussed on page 40. Few. people appreciate that even in an ordinary frying operation effective results can not be obtained unless the vessel position is close enough to the flame so that the tip of the flame can deliver the heat generated in an effective manner. Even with high pressure and long flames, if a strong draft should deflect the flame the cooking service will be unsatisfactory.

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[1] Few people appreciate that even if the service averages below normal 5 hours a day for 17 days, the total period of normal service is still more than 99 per cent.

When mantle burners are opened so as to admit more gas than is necessary, the familiar "hissing" or blowing sound is produced. This has, first, a tendency to break the mantle and chimney; second, waste the gas; and, third, lowers the candlepower of the lamp. The majority of natural gas consumers do not appreciate that gas burners need care and attention and that periodic cleaning is absolutely essential if satisfactory results are to be obtained.

The data given on page 40 show the marked differences in results that may be obtained in using natural gas in the fire pot of an ordinary coal furnace, as against a specially built natural gas furnace.

BAROMETRIC CHANGES MAKE MORE DIFFERENCE ON TOTAL PRESSURE THAN GAGE PRESSURE VARIATION.

On account of the changing atmospheric conditions, the barometric pressure varies from day to day and from hour to hour on the same day. Thus, the atmospheric pressure at Louisville, Ky., on January 21, 1918, was 30.47, and on January 11 was 29.19 inches, this difference of 1.28 inches of mercury being the equivalent of 0.627 pound to the square inch, or 10 ounces to the square inch, or considerably more than the entire range of variation in gage pressure.

ATMOSPHERIC TEMPERATURE CHANGES HEATING VALUE OF GAS MORE THAN CHANGES IN GAGE PRESSURE.

The variation in mean monthly temperature of natural gas at Louisville, Ky., is shown on page 45.

The variation in temperature of natural gas in the underground mains makes more difference in the heating value than the variation in gage pressure. The maximum fluctuation in temperature produces a difference in heating value of about 5 per cent, while the maximum fluctuation in pressure produces a difference in heating value of less than 4 per cent. Furthermore, these variations work in opposite directions; that is, in winter time when the pressure is low, therefore tending to decrease the heating value, the temperature is low, tending to increase the heating value. This increase due to low temperature will always be more than the decrease due to low pressure.

EFFECT OF PRESSURE OR TEMPERATURE CHANGES ON HEATING VALUE OF GAS.

These will produce changes in volume, but will neither destroy nor create any heat units, and hence will neither increase nor decrease the total number of heat units contained in the gas. However, the volumetric changes will always alter the distribution of the total number of heat units, as follows:

Gage pressure above atmosphere.	Relative British thermal unit.	Relative per cent.	Gage pressure above atmosphere.	Relative British thermal unit.	Relative per cent.
Ounces.			*Ounces.*		
8	1,034	103.4	3	1,013	101.3
7	1,030	103	2	1,009	100.9
6	1,026	102.6	1	1,005	100.5
5	1,022	102.2	0	1,000	100
4	1,017	101.7			

Gas temperature.	Relative British thermal unit.	Relative per cent.	Gas temperature.	Relative British thermal unit.	Relative per cent.
° *F.*					
70	960	96	50	1,000	100
65	970	97	45	1,010	101
60	980	98	40	1,020	102
55	990	99	35	1,030	103

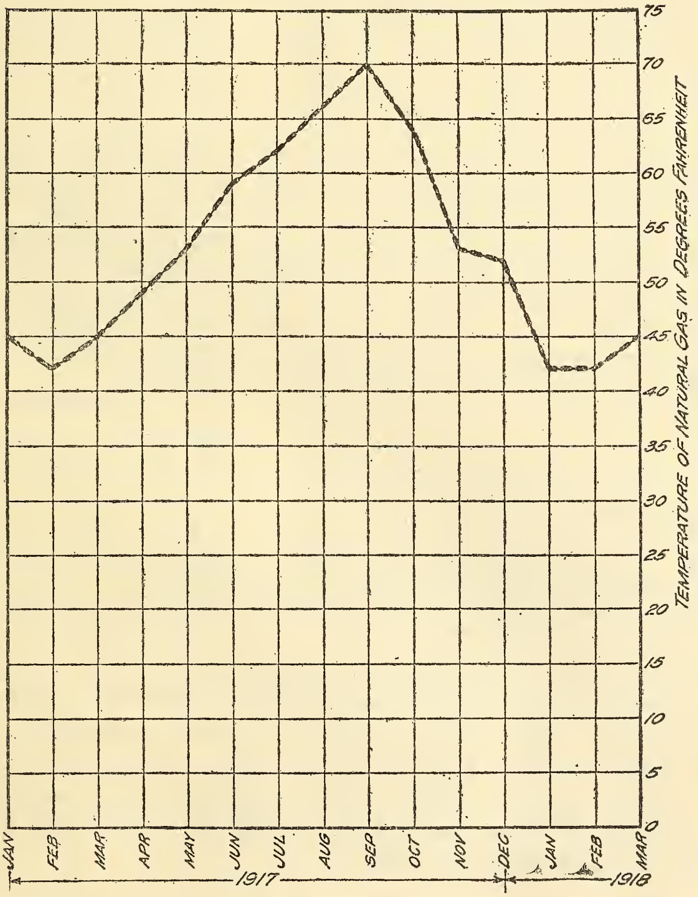

FIG. 17.—MEAN MONTHLY TEMPERATURES OF NATURAL GAS IN GAS MAINS.

COMBUSTION OF NATURAL GAS.

The combustible constituents of natural gas are made up of combinations of the elements carbon and hydrogen. When natural gas is burned so as to secure perfect combustion, only carbon dioxide and water vapor are formed. That is, the carbon of the gas unites with the oxygen of the air forming carbon dioxide, and the hydrogen of the gas unites with the oxygen of the air forming water vapor. The water vapor, of course, will condense when cooled. This water vapor does not come from the gas, but is created and formed by the chemical action of the hydrogen in the gas and the oxygen in the air.

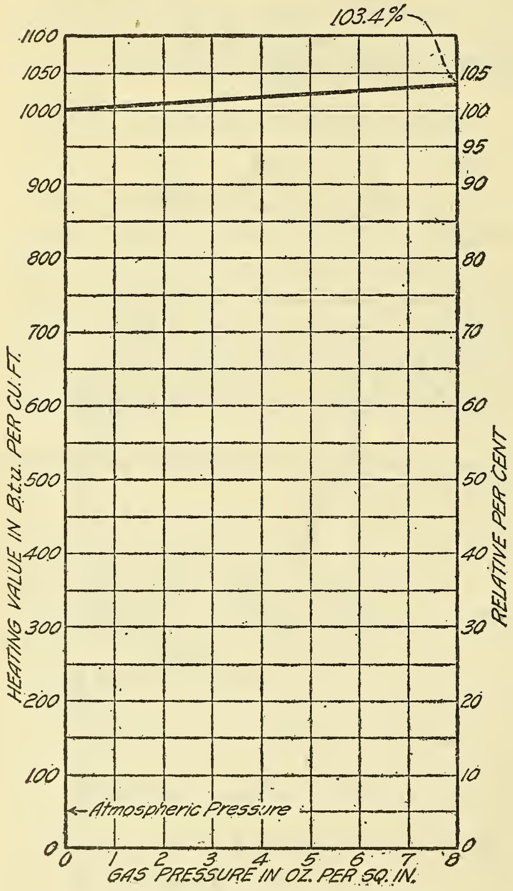

FIG. 18.—CURVE SHOWING EFFECT OF GAS PRESSURE ON GAS VOLUME AND GAS HEATING VALUE.

Each cubic foot of natural gas burned requires approximately 9½ cubic feet of air, forming 10½ cubic feet of combustion products, which are made up of 2 cubic feet of steam, 1 cubic foot of carbon dioxide, and 7½ cubic feet of nitrogen, all thoroughly diffused through each other.

The combustion of 1,000 cubic feet of natural gas will form 2,000 cubic feet of water vapor or steam, and this when condensed will make approximately 10½ gallons of water. This is not peculiar to natural gas, but is true of all gases containing hydrocarbon compounds. One thousand cubic feet of manufactured gas will form about one-half the water vapor produced by the combustion of 1,000 cubic feet of natural gas. It is this water vapor that causes the bakers and broilers of stoves to rust, and where gas is used in open fires without flues, or for lighting, makes the walls and windows sweat and glued furniture open up.

If the combustion is not perfect, then carbon monoxide, which is a deadly poison, may be formed. The toxic action of this is so marked that one-tenth of 1 per cent is enough to produce fatal results. This is especially likely to be formed when a flame is suddenly impinged on a cold surface, as, for instance, the first few seconds' operation of an instantaneous hot water heater.

EFFECT OF ATMOSPHERIC TEMPERATURE ON DEMANDS FOR GAS.

The temperature of the atmosphere has a direct bearing on the demands for natural gas for heating service. However, the quantity of cooking, incidental hot water heating, and lighting is independent of the temperature of the atmosphere and would be practically constant for the year. The humidity of the atmosphere, direction and velocity of wind, and hours of sunshine, also affect gas consumption, as far as heating service is concerned. In general a high wind causes more of an increase than merely a low temperature. The mean monthly temperature curve plotted upside down will always show a close relationship between volume of gas used and temperature of atmosphere.

DAILY DEMANDS FOR GAS HEATING SERVICE.

The daily gas heating consumption to each degree of temperature below 70° F., at Louisville, Ky., from mean temperatures ranging from 2° on February 2 to 58° on January 29, is shown below.

It will be noted that the heating service for each degree is larger at the warmer temperatures. This is because the general tendency is to keep most houses at a higher temperature than necessary, and for this reason on account of the cheapness of the gas, and the general absence of thermostat control devices, the gas is not used as efficiently.

Daily gas heating consumption for each degree of temperature below 70° F.

Date.	Mean temperature of atmosphere, degrees F.	Difference between mean temperature and 70°, 70–A.	M cubic feet natural gas a day.			
			Delivered to Louisville.	Service independent of atmospheric temperature.	Heating service.	Heating service per degree below 70° F. (E÷B).
	(A)	(B)	(C)	(D)	(E)	(F)
1917.						
Feb. 2	2	68	13,209	4,500	8,709	128
Jan. 14	10	60	12,193	4,500	7,693	128
Jan. 11	20	50	11,370	4,500	6,870	137
Jan. 26	30	40	10,869	4,500	6,369	159
Jan. 6	39	31	9,142	4,500	4,642	149
Jan. 3	48	22	7,852	4,500	3,352	152
Jan. 29	58	12	6,830	4,500	2,330	194
Average						150

MONTHLY DEMANDS FOR GAS HEATING SERVICE.

When the atmospheric temperature drops below 70° F. demands for heating service are created which are practically proportional to the number of degrees that the atmospheric temperature is below 70. The variation in monthly demands for each degree of atmospheric temperature below 70° F. is shown in the following table.

The data in column D is the estimated gas consumption for cooking, incidental hot water heating, and lighting, which is entirely independent of the atmospheric temperature, and the estimated figure is taken approximately as the total amounts delivered during the months of June, July, August, and September, when there are practically no demands for heating service.

The average of the demands for heating service at Louisville, Ky., for each degree below 70° F., for the months of January, March, April, May, October, and November, 1917, and March 1918, when enough gas was available to meet the demands, was 5,500,000 cubic feet for each month for each degree below 70° F.

Monthly gas heating consumption for each degree below 70° F.

Date.	Mean monthly temperature of atmosphere, in degrees F.	Difference between mean temperature and 70° F., 70-A.	Million cubic feet natural gas a month.			
			Delivered to Louisville.	Service independent of atmospheric temperature.	Heating service (C-D).	Demands for heating service per degree below 70° F. (E÷B).
	(A)	(B)	(C)	(D)	(E)	(F)
1917.						
January	36	34	302	140	162	4.8
February	32	38	260	140	120	3.2[1]
March	46	24	260	140	120	5
April	55	15	232	140	92	6.1
May	60	10	204	140	64	6.4
June	72		140			
July	76		131			
August	76		134			
September	69		149			
October	51	19	243	140	103	5
November	45	25	270	140	130	6.2
December	26	44	269	140	129	2.9[1]
1918.						
January	20	50	263	140	123	2.4[1]
February	38	32	223	140	83	2.5[1]
March	51	19	232	140	92	4.9
Average of normal months.						5.5

[1] Not enough gas available to meet demands.

WHY STANDARDS FOR NATURAL GAS SERVICE MUST BE LOWER THAN FOR MANUFACTURED GAS.

The operating conditions in a natural gas plant are so different from those prevailing in a manufactured gas plant that the standards of service that would reasonably be applicable to the latter would not be feasible or expedient with natural gas, because:

1. The volume of natural gas business for each domestic consumer is generally about five times as large as for manufactured gas.
2. The peak load difficulties in a natural gas load are much more troublesome than in manufactured gas, due primarily to the heating load, which fluctuates with the atmospheric temperature.
3. The service standards can not be limited to merely the distributing plant limits, but would be closely related to the main pipe lines, back into the field to the compressing stations, and general field operating conditions.
4. The natural gas company can not create the basic feature of the service it is selling to the public, but must depend entirely on the caprice of nature for this.
5. Every foot of gas sold represents in effect the sale of a part of the company's property.
6. Since there is no regeneration, the supply can be kept continuous only by constant and persistent hunting for new supplies.
7. Although the distributing end is a public utility service, the field or producing end is a mining proposition, and the continuous connection of the two by the transmission line has the immediate effect of also connecting the mining hazards to the distributing end of the business.
8. The migratory tendencies and fugitive nature of natural gas under the ground make its reduction to possession much more difficult than for solid minerals.
9. In general, the prices for natural gas service have not been adequate, and have not been made on the basis of rendering as uniform a condition of service, especially with regard to pressure, as can be maintained in a manufactured gas plant.
10. Both the quality and quantity are entirely controlled by nature.

DISCOUNT FOR LOWER PRESSURES STIMULATES WASTE.

A penalty clause providing for a discount when pressures less than 4 ounces are maintained has been suggested as a means of guaranteeing good service. However, instead of guaranteeing service it stimulates waste for the reasons given on page 54. The penalty clause is inequitable and fails to recognize the well known operating characteristics of the mining, transmission, and distribution of natural gas, which, therefore, differentiate this from every other type of public utility service, more particularly by:

1. Failure to recognize that the heating value of the gas does not decrease proportionally with the decrease in gage pressure.
2. Failure to recognize that neither the efficiency nor the efficacy of gas decreases proportionally with the decrease in gage pressure.
3. Failure to recognize that higher efficiencies may be obtained at pressures below 4 ounces than at 4 ounces and above.

4. By ignoring rate of flow or volume of gas to be delivered and the close relationship that exists between volumetric demands and the constantly changing and uncertain and unpredeterminable atmospheric temperature changes.

5. General conservation methods in the field have not been followed in the past; gas has been produced, transmitted, and distributed in a most wasteful manner, which has, therefore, very greatly depleted available supplies, highly desirable for peak-load service.

6. The uncertain, migratory, and fugitive nature of the gas in the underground reservoirs, where it is entirely beyond the control of the human will, legal process, or contractual relationship, and yet where its expansive properties under the ground must be taken as the initial step for the delivering of service to consumers 200 miles away, obviously makes it evident that considerable leeway must be allowed in service standards.

EXTENSION OF SERVICE.

In considering the question of the desirability of making new extensions after a natural gas supply has become depleted, so as to make satisfactory service for all impossible, two distinct viewpoints have been developed, namely:

The Indiana Supreme Court in 1901 held that:

> A natural gas company * * * can not refuse to permit connections with its mains by unsupplied citizens because the gas pressure has fallen so low that existing customers can not be adequately supplied, and that the court should compel the company to permit participation in the supply of gas furnished by it, although it can not furnish enough to satisfy the needs of its existing customers. (State of Indiana ex. rel. Wood *versus* Consumers Gas Trust Co., 55 Lawyers Reports, 245.)

The New York Public Service Commission, second district, in 1915, held that:

> Consideration must be given to a safe and adequate service on the part of the company, within its means and facilities, and if service of this character is being given to a comparatively few customers in a certain locality, with the eliminated amount of gas available for such purpose, it is manifestly the duty of this commission to permit the continuance of such service rather than order the company to turn its gas into a larger field where a safe and adequate service could not be given. (New York Public Service Commission, second district, North Tonawanda case No. 4478, Feb. 25, 1915.)

The Indiana viewpoint is merely a blind following of obsolete precedent. Furthermore, it is based on the erroneous theory that it is a matter of no consequence whether adequate service can be given to any customers, so long as all of the customers stand on an exact equality, and fails to recognize that there is a clear distinction between equity and equality, and that the two are not synonymous.

The New York viewpoint is in accordance with the spirit and letter of up-to-date public utility regulation and recognizes the inherent characteristics and natural limitations of the natural gas industry, and that usable service to a limited number is better than poor or no service to a large number. This New York viewpoint is the just and equitable one to apply to all new service extension problems, as well as to the inevitable problem that will arise in the near future, of limiting or discontinuing the service entirely in certain localities, because the available supply as furnished by nature will not permit the continuance of a usable service to all.

WASTE AND CONSERVATION OF NATURAL GAS.

DEFINITION OF CONSERVATION.[1]

True conservation is not hoarding, but the wise use of natural resources, and it implies not merely the preserving in unimpaired efficiency, but also a wise and equitable exhaustion with a maximum efficiency and a minimum waste. The heart of the natural gas conservation problem is the conflict between the present and the future. The individual land owner is interested primarily only in immediate present personal returns. That is, he is thoughtless and indifferent with respect to the future. The public—at least the 2,000,000 domestic natural gas consumers and the 10,000,000 people dependent on natural gas for their cooking, heating, and lighting purposes—are interested in conserving the supply and bringing about a slow, wise, and economical exhaustion, so as to insure continuity of service for the future.

Conservation, therefore, demands intensive rather than extensive use, takes cognizance of equitable distribution, aims to bring about social justice, and means the greatest good to the greatest number—and that for the longest time.

EXTENT OF WASTE.

Most of the supply and service problems of to-day are the inevitable result of waste in producing and handling natural gas. The annual reports of the conservation committee of the Natural Gas Association of America are stinging indictments of a criminal system, fostered by both the gas companies and the public, that has resulted in wasting more gas than has ever been utilized. The following expert opinions further reflect this appalling situation:

> The history of the natural gas industry of the United States is an appalling record of incredible waste, but it must be told, in order to explain the need for the remedies proposed.[2]

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[1] Phraseology suggested by Prof. C. R. Van Hise's The Conservation of Natural Resources in the United States, and Prof. Richard T. Ely's Conservation and Economic Theory. Trans. Amer. Inst. Min. Eng., vol. 54, p. 458.

[2] Technical Paper 38, United States Bureau of Mines, Waste in the Production and Utilization of Natural Gas and Means for their prevention.

> In my own State of West Virginia only eight years ago not less than 500,000,000 cubic feet of this precious gas was daily escaping into the air from two counties alone, practically all of which was easily preventable by a moderate expenditure for additional casing.[1]

> Of all the pieces of extravagance of which the American people have been guilty, perhaps their reckless and wasteful use of natural gas is the most striking—not the most important—but the most striking. This product, severely limited in quantity, which can last only a few years at most, has been handled by us as if it were illimitable.[2]

> In reference to natural gas, the great and pressing necessity is to stop its appalling waste by enacting and enforcing proper legislation. This ideal fuel should be used with the severest economy in order to prolong its life, which will be brief at best.[3]

Had the pioneer far-reaching waste eliminating recommendations of Dr. Edward Orton, State geologist of Ohio, and Dr. I. C. White, State geologist of West Virginia, been heeded, most of the acute natural gas service problems of to-day would not exist.

SPECIFIC FORMS OF WASTE.

The various forms of waste may be grouped under drilling, well operation, transmission, and utilization operations.

DRILLING WASTES.

1. *Not closing wells promptly.*—Much gas is wasted on account of delay in closing wells, caused primarily by poor judgment and failure to supply material promptly. In many cases the rock pressure over quite a district has been materially lowered by the delay in closing promptly a single large well in that section.

2. *Improper casing.*—There is much underground waste by improper casing methods which allow gas or water to migrate from their original strata into other strata. This is an especially important feature in the West Virginia fields, where in many instances several gas-bearing formations are superimposed with intervening barren formations.

3. *Waste of gas to air.*—As a result of improper casing methods gas frequently works up around the packer or into the casing above the packer and is wasted in the air.

4. *Gas waste in well-drilling boilers.*—Most gas burning appliances used in well-drilling boilers are crude and inefficient, and the gas is handled as if it had practically no value and were of little use to other people.

5. *Waste of gas in torches.*—A large number of open flame (flambeaux) torches are still in use. Not only is this an inefficient and

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[1] I. C. White, State geologist of West Virginia. Address at conference on conservation of natural resources, May 13, 1908.

[2] C. R. Van Hise's The Conservation of Natural Resources in the United States, p. 60.

[3] Idem, 360.

therefore wasteful method of securing illumination at night but in many instances the torches are not shut off during the day.

6. *Offset wells.*—The drilling of offset wells is not only frequently a waste of capital, resulting from overdrilling, but very frequently results in marked waste of gas. This is discussed in further detail on pages 55–57.

7. *Improper plugging.*—Where a well is abandoned and the casing pulled, if the hole is not properly plugged, it may result in the ruination of other gas bearing formations by the migrating of gas or water from one to the other, or the very great waste of gas leaking into coal veins or coming up and passing out into the air.

WELL OPERATION WASTES.

1. *Wasting gas to get oil.*—Where oil and gas are found in the same field it is quite a general practice for oil operators to blow off the gas, that is, waste it, in order to procure the oil. This is the principal cause of the depletion of many gas fields, and is responsible for a greater volume of gas waste than probably all other causes put together.

In tests on over 1,000 oil wells in West Virginia it was shown that the waste of natural gas of each well was at the rate of 12 M cubic feet a day, or 4,380 M cubic feet of natural gas a well per annum. There are at least 16,000 oil wells in West Virginia, and at this rate the annual waste from this source would be at least 70,000,000 M cubic feet of natural gas, equivalent to about one-third of all the natural gas used for domestic consumption in the United States.

2. *Excessive blowing.*—Where wells are blown into the atmosphere for water freeing purposes the gas must, of course, be wasted. However, in many cases the wells are blown longer than necessary, and in others it would be feasible to install siphons for the removal of the water so as to curtail this form of waste.

3. *Salt water troubles.*—In some instances salt water exists in the gas-bearing formation and in others it works in from other strata, due primarily to improper drilling and casing methods. This results in a large waste of gas when the wells must be watered to free them of the salt formation below in the tubing.

4. *Too rapid lowering of the rock pressure.*—The irregular or too rapid lowering of the rock pressure by exceedingly rapid production will always produce undesirable operating conditions, and must ultimately result in a large waste of the total amount of gas that might have been removed with more rational operating methods.

TRANSMISSION WASTES.

1. *Leakage.*—The structural conditions accounting for much of the leakage along gas lines are discussed in detail on page 58. The

leakage in the consumer's house piping beyond the meter is very much larger than ordinarily appreciated. In a number of houses where the leakage has been checked it has been found that in their instances the leakage averaged 19 M cubic feet of gas a year for each house.

2. *Measuring devices curtail leakage.*—The leakage problem is very much greater than ordinarily appreciated, due to the fact that in so many instances measuring appliances are not used for measuring the gas either into the line or out of the line. The more extensive use of measuring devices, if properly installed and the results properly interpreted, would reveal an enormous waste in many lines that are now supposed to be tight.

3. *Blowing drips.*—If the gasoline vapors and water vapor are not removed by drying the gas, considerable gas must be wasted where these vapors, after they have been precipitated in liquid form, must be blown out along the transmission system. The installation of gas drying plants will therefore practically eliminate this form of waste in addition to conserving the gasoline.

UTILIZATION WASTES.

1. *Flat rate.*—Much natural gas is still sold at a flat rate of so much per consumer, or so much for each fire or other fixture. This puts a premium on waste and results in the destruction of an enormous amount of gas that might be conserved for more intelligent and appreciated future use.

2. *Cheap gas for manufacturing.*—When natural gas is sold at low prices for industrial use, there is no incentive to use the gas in an efficient manner, and it is therefore quite frequently used without regard to efficiency or conservation. This is probably the largest form of waste in connection with utilization of natural gas.

3. *Free gas.*—In many cases boom towns in the gas fields have held out the inducement of supplying either free gas or the gas has been sold at ridiculously low prices for industries that would locate there. This feature has been especially troublesome in West Virginia and has resulted in depriving many domestic consumers of an adequate supply of the best fuel available for household use.

In an extensive investigation the amount of gas consumed by domestic consumers in West Virginia having free gas service privileges, on account of having gas wells or gas lines on their farms, it was found that the average consumption per free consumer a year was 480 M cubic feet. This is a waste of at least 350 M cubic feet for each free consumer a year. There are at least 4,400 free consumers in West Virginia, and at this rate of waste this item alone amounts to 1,540,000 M cubic feet a year. This is more than half the amount of gas used in Louisville. The following further emphasizes this form of waste:

Average annual consumption for each free domestic natural gas consumer in West Virginia, 480 M.

Average annual consumption for each domestic natural gas consumer in the United States, 100 M.

Average annual consumption for each domestic consumer at Louisville, 53 M.

4. *Carbon black.*—This is a form of improper use rather than absolute waste. The carbon black industry in West Virginia uses 50 per cent more gas than is furnished to all of the domestic natural gas consumers in that State. The economic reasons accounting for the use of natural gas for carbon black manufacture are discussed in detail on pages 60–62.

5. *Inefficient use.*—In many cases natural gas is used without mixers. The data given on page 40 show the marked difference between the use of natural gas in the fire pot of an ordinary coal furnace and a correctly designed natural gas furnace, and the cooking stove and lighting efficiencies emphasize the need of improvements in gas-using appliances.

6. *Thermostat control.*—Thermostats for controlling house-heating appliances are out of the experimental stage, and the large number in use demonstrates their reliability and usefulness. In addition to ministering to the comfort of the house occupants, they aid very materially in conserving the gas consumption by preventing overheating. Where natural gas is sold at low prices the practice is still all too common of lowering the temperature of an overheated room by opening a window rather than by lowering the gas fire.

7. *Discount for low pressure stimulates waste.*—In a number of instances consideration has been given to a penalty clause providing for a discount when pressures lower than 4 ounces are maintained. This has the immediate practical effect of lowering the price of gas during the peak load period and stimulates waste, for the well-known human nature reason that what is made cheap will not be saved. When the consumer believes that his bills will be lower he will attempt to use more gas than he otherwise would, and in this way the cumulative effect will be to still further lower the standard of service to all, in addition to using the gas in a wasteful manner at a time when every thought should be for conservation of the highest order. Whatever may have been the motive for considering the penalty clause, there can be no doubt but that its effect is abortive.

DEFINITION OF "OFFSET WELL."

After a well has been drilled on one farm, the term "offset well," in a narrow sense, means a well drilled on a contiguous farm, directly opposite from the first well and substantially the same distance across from the farm line.

It is not necessary in all cases that the offset well be either directly opposite to or the same distance from the property line as the well that it is to offset. Thus one well may be an offset to two or more contiguous wells. In other cases the shape of the tract will determine the position of the offset well. The primary feature to be borne in mind is that the offset well is drilled for purposes of protection, and that this is more important than hard and fast rules regarding exact location. The adventitious origin, migratory habits, and fugitive tendencies of natural gas, as well as the nature of the sand and the topography of the country, are also factors that must be considered.

DRILLING OFFSET WELLS MAY MAKE EXISTING WELLS COMMERCIALLY WORTHLESS.

In gas territory the lessee may sink many wells and find gas in them all, but he can utilize only such of them as have a volume and pressure sufficient to enable him to transport the gas through his line and deliver it to the purchaser. If no one of them has the requisite pressure, then no one of them can be utilized; the gas must be wasted, the cost of the wells will be lost, and the lessor entitled to no royalty. What is the proper way to operate a gas lease is therefore a question beset with some difficulty. Its settlement requires some general knowledge of the business and some knowledge of the local field. The lessee may have a good well, from which he can utilize the gas with profit. He may put down another on the same farm and thereby so reduce the pressure in the first as wholly to destroy its value, without getting a sufficient pressure at the second to enable him to utilize that. The gas, if coming from one well, would be of great value. Divided in such manner that the whole volume and pressure at each is below the necessary standard, the whole is lost.[1]

WHY OFFSET WELLS ARE FREQUENTLY DRY.

It is a matter of common observation in natural gas mining that offset well locations are frequently dry holes. This is because most natural gas pools are not strictly continuous, but are made up of many small local pools, frequently surrounded in whole or in part by a gas rock of low porosity. For this reason, if a producing well has been drilled into one of these small local gas pools, there is a large chance that the offset well location may go beyond the limits of the pool and therefore be a dry hole.

WHY OFFSET WELLS ARE FREQUENTLY OF LOW CAPACITY.

The fact that offset natural gas wells are frequently of lower capacity than the wells that they offset may be accounted for as follows:

If the offset well is drilled at the extreme edge of a small local pool its capacity would naturally be smaller than the original well drilled more nearly in the center of the pool. Furthermore, when the first well is drilled into the pool the rush of gas from the then high rock pressure has a marked tendency to open up numerous channels of low resistance in the rock formation, so that the gas in the gas sand can get to the well opening with a minimum of friction. The high initial rock pressure aids substantially in first creating such lines of least resistance and then in freeing them of loose particles of sand which are blown out through the well. Even though an offset well is afterwards drilled in the same pool, the initial rock pressure will probably be lower than for the first well, and the lower gas pressure will not be near as likely to produce favorable conditions for flowing to the bottom of the offset well as were produced in the first well.

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[1] Pennsylvania Supreme Court. McKnight *versus* Manufacturers Natural Gas Co. (146 Pa. St., p. 185).

WHEN IS THE DRILLING OF OFFSET WELLS JUSTIFIABLE?

The crux of the entire "offset well-drilling question" is whether the decision to make the additional investment in drilling offset wells for natural gas, providing the increased annual operating cost for their care and maintenance and cutting down the reserve acreage necessary for future continuity of service, shall be made by the farmer—with no risks involved and no obligation to the public—or the party who must provide the money, assume the financial risk and operating duty to the public. The following correctly expresses the equities of the situation: The development and protection of lines which is implied is such as is usually found in the business of an ordinary prudent man. The operator, who has assumed the obligations, has put his money and labor into the undertaking, and is now called upon to determine whether it will pay to spend some thousands of dollars more in sinking another well to increase the production of the tract, is entitled to follow his own judgment, if that is exercised in good faith, in accordance with the doctrines laid down on page 65.

PUBLIC PAYS FOR WASTEFUL OPERATION.

While the production of natural gas is strictly a mining venture, its distribution to the ultimate consumer is distinctly a public utility service. Even under State regulation of public utilities, any marked increase in the cost of natural gas mining operations will soon be reflected in the price the ultimate consumer must pay for the natural gas service.

The acreage data given in figures 5, 6, and 7 show that not every landowner can have an offset well. The drilling and operation of unnecessary offset wells will represent a large increase in the capital investment and operation cost of natural gas companies. All of such increased burdens represent an unnecessary waste which will ultimately be paid for by the public.

The following analysis gives the reasons for the drilling by one company of 429 wells in West Virginia during 1916, and emphasizes the offset well burden, as well as the large number that were drilled on the demands of the lessors.

Reason for drilling:	Number of wells.
To save lease	96
Offset	68
For oil	74
For gas	52
Wildcat	4
Requirements of lease	5
Demand of lessors	130
Total	429

GAS LEAKAGE.

The difficulty in keeping gas joints tight is not ordinarily appreciated and results in an enormous waste from defective joints and minute openings in gas-carrying equipment. The laws controlling gas leakage may be stated as follows:

1. The relative leakage tendencies of any two fluids under the same conditions are practically inversely proportional to the square roots of their respective densities. Natural gas has a density of practically 0.64. With regard to air, the relative leakage of air and natural gas will vary as the square root of 1 and square root of 0.8 or as 1 is to 0.8. That is, the leakage tendency of natural gas will be $1 \div 0.8 = 1.25$ times that of air under similar conditions. Water has a density 819.5 times heavier than that of air; hence leakage tendency of natural gas in comparison to that of water at the same pressure is much greater than that of water. This accounts for the universal difficulty in keeping gas confined without leakage.

2. The quantity of leakage through a given opening will vary directly as the square root of the differential pressure.

3. Amount of leakage is independent of the quantity or velocity of gas passing through the main. In other words, the pressure remaining the same, the leakage will be just as much during the period of low gas consumption as during the period of high gas consumption.

A typical gas main joint coupling, as shown on page 59, has four surfaces adjacent to the rubber and the metal where leakage may be possible. On a 16-inch main each coupler presents about 17 linear feet of such potential leakage surface. The magnitude of this in a large system is evident when we consider that about 270 couplers will be required to the mile, thus making $270 \times 17 = 4{,}590$ feet of possible leakage surface to the mile of a 16-inch gas main.

Welded gas mains are coming into use, but the welded process can not be used except on new work or in such main line installations where the entire line can be shut down and drained of all gas before the welding operation is attempted.

DEFINITION OF CARBON BLACK.

In the American trade the term "lamp black" is usually understood to be a soot deposited by the smudge process and made from oil, rosin, or some other solid or liquid raw material, whereas "carbon black" is the term applied to a black deposited by actual contact of a flame upon a metallic surface.[1]

WASTE IN CARBON BLACK MANUFACTURE.

Carbon black is now made by the wasteful process of incomplete combustion of natural gas. That is, the gas is simply burned in the open and the flame impinging against a metal plate makes the black deposit known as carbon black. From $1\frac{1}{8}$ to $1\frac{1}{2}$ pounds of carbon black are made to each M cubic feet of gas burned. The only product obtained is the carbon black, and this utilizes only a very small percentage of the total carbon content of the gas.

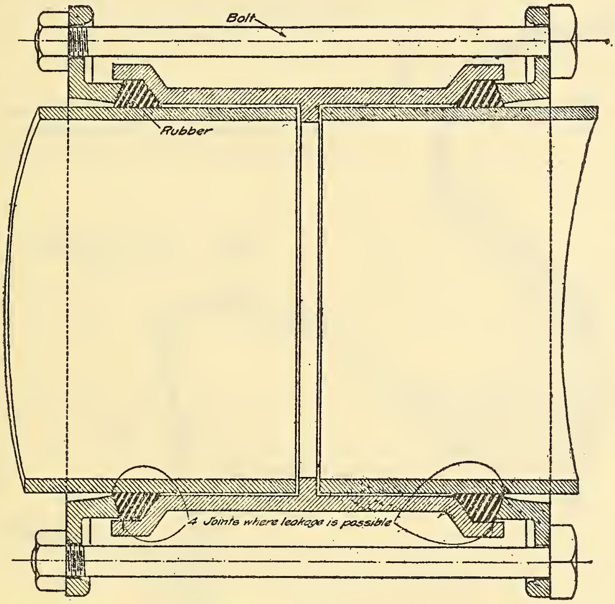

FIG. 19.—LONGITUDINAL SECTION OF GAS PIPE COUPLER SHOWING FOUR POSSIBLE LEAKAGE JOINTS.

The total annual quantity of natural gas used for carbon black manufacture is more than 26,000,000 M cubic feet. This wastes about 10 times as much gas as was used in the city of Louisville, or the equivalent of one-eighth of the domestic natural gas consumption in the United States.

Dr. J. B. Garner, of the Mellon Institute of Industrial Research, Pittsburgh, Pa., has demonstrated that with correctly designed appliances the yield of carbon black can be made three times as high as that usually obtained by the wasteful process of incomplete combustion, and in addition thereto save a usable commercial gas.[1]

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[1] U. S. Geological Survey Statistics. Natural Gas in 1916, p. 662.

WHY CARBON BLACK MANUFACTURE MAY BE MORE ATTRACTIVE THAN PUBLIC UTILITY SERVICE.

1. *No regulation.*—Not carrying with it any public duties, it is not subject to the many phases of public regulation that control the marketing of natural gas as a public utility service.

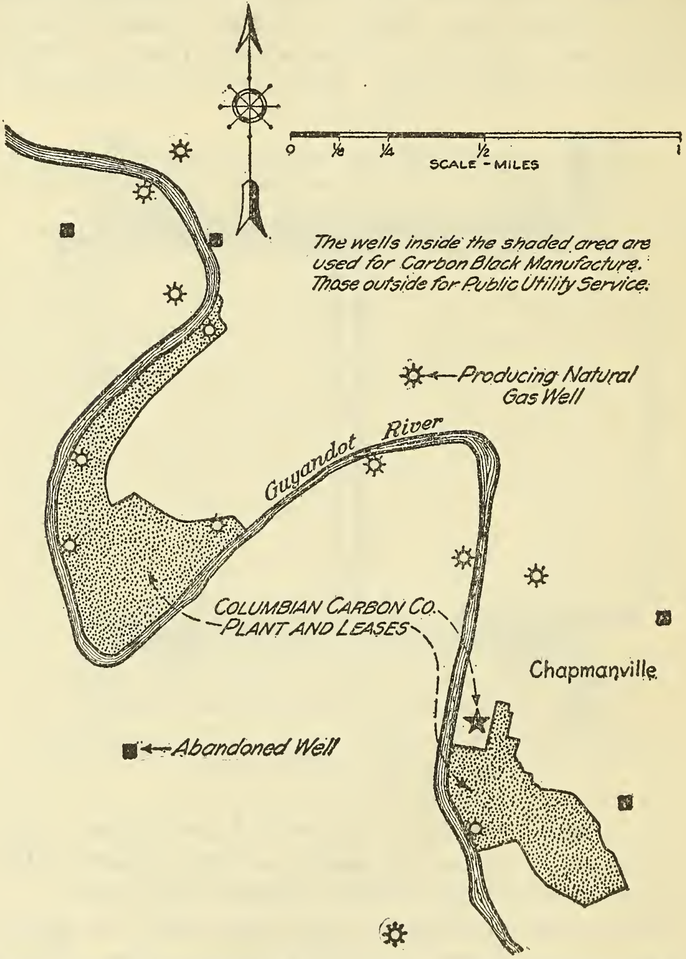
0 1/8 1/4 1/2 1
SCALE - MILES
The wells inside the shaded area are used for Carbon Black Manufacture. Those outside for Public Utility Service.
Producing Natural Gas Well
Guyandot River
COLUMBIAN CARBON CO. PLANT AND LEASES
Chapmanville
Abandoned Well

FIG. 20.—MAP SHOWING COMPETITION FROM CARBON PLANT AT CHAPMANVILLE, W. VA.

2. *Price.*—This is not controlled by rate fixing bodies, but is limited solely by the ordinary laws of trade, and is, therefore, more attractive from the investor's viewpoint than governmental price fixing.

3. *No transmission lines necessary.*—The plants are located in the fields, as shown in figure 20, close to the leases, and sometimes on

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[1] J. B. Garner The Chemical Possibilities of Natural Gas. Paper, Natural Gas Association of America, Pittsburg meeting, May 23, 1918.

the leases themselves, so that the ordinary gathering lines are the only transmission equipment necessary, and these are so short as to not even require the use of gas compressors. This, of course, makes a marked difference in leakage loss, due to short lines, as well as installation cost.

4. *Uniform load.*—A natural gas plant operating as a public utility, as shown in graphical form on page 37, can use its total equipment only about one-third of the time. That is, it has a load factor of only about 34 per cent. The carbon plant load is uniform every hour in the day and for every day in the year. With the same wells and gathering line equipment it can, therefore, handle approximately three times as much gas as it could if it were selling its gas to the public as a public utility service.

5. The proximity of the carbon plants to the wells, with the resulting short lines, makes it possible to carry lower well pressures than can ordinarily even be reached by contiguous public utility companies having their wells discharge into intake lines to compressor stations. This, in most cases, gives the carbon plant the advantage in pressure over the adjacent competing public utility plant.

6. In a number of instances carbon plants have been located where it would not be feasible, with present prices for natural gas, to lay lines in order to transmit the gas into the public utility transmission systems.

7. The carbon black plants do not carry reserve acreage, as a general rule, and this lowers the capital necessary for the enterprise.

8. The plant hazards are much less than those in a public utility plant.

9. The investment necessary for each 1,000 cubic feet of natural gas handled will be about 10 times larger in a public utility plant than in a carbon black plant, as explained in further detail in the next section.

SMALL CAPITAL IN CARBON BLACK PLANT AS COMPARED TO PUBLIC UTILITY PLANT.

It is not ordinarily appreciated that the investment necessary to render natural gas service is very much greater to each consumer than for any other utility service. That is, the investment to each consumer in natural gas properties, from gas leases to domestic meters, is—

1. Three hundred per cent more than in electric plants, thus requiring $4 investment in natural gas plants to $1 in electric plants for each consumer.

2. One hundred and fifty per cent more than in waterworks plants, thus requiring $2.50 investment in natural gas plants to $1 in waterworks plants for each consumer.

3. One hundred per cent more than all of the Bell Telephone toll lines and Bell exchanges in the United States, thus requiring $2 in-

vestment in natural gas plants to $1 in telephones for each consumer.

4. Fifty per cent more than in ordinary manufacturing gas plants, thus requiring $1.50 investment in natural gas plants to $1 in manufacturing plants for each consumer.

The investment from reserve acreage to domestic consumer's meters in a natural gas plant rendering public utility service and selling on an average of about 100 M cubic feet of natural gas to each domestic consumer a year will be about $220 to each consumer, or $2.20 for each M cubic feet of gas delivered a year.

The investment in a carbon black plant for each M cubic feet of natural gas that may be used a year, taking into account all of the favorable factors enumerated in the preceding section, will be only about 20 cents for each M cubic feet.

This is an unappreciated factor that must be reckoned with in future natural gas service standards.

COMPETITION ALWAYS ECONOMIC WASTE.

Competition in a gas field always results in a duplication of lines, unnecessary wells, enhanced operating cost, lack of proper coordination, failure to remove all the gas, and shortened life of the field, with the inevitable resulting injury to the domestic consumer.

Under competitive conditions, even where the underground gas reservoir is made up of many local pools, various operators will drill into the same local pool, and thus drain out the gas from under each other's leaseholds.[1]

EASE IN DRILLING INVITES COMPETITION.

The easier it is to drill a well in any given territory, the more wells will be drilled by small and inexperienced operators, and the greater will be the inefficient operation of the field. Furthermore, the indiscriminate drilling by inexperienced local operators always tends to increase the use of gas for manufacturing purposes, and takes the gas out at the fastest possible rate, thereby decreasing the effective life of the pool.

CRITICAL NEED OF THE NATURAL GAS INDUSTRY.

The natural gas industry is in a transition stage, going from the large volume and low-priced basis of the past to the small volume and inevitably higher price of the future. Strong individualism dominated the past. Public policy will ultimately require that legalized and regulated collective cooperation rather than cut throat competition, dominate the future. The greatest need of the industry to-day is the adequate recognition of the dominating factors in the natural gas conservation problem, which are:

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[1] For further discussion see United States National Museum Bulletin 102, Part 6, on Petroleum: A Resource Interpretation.

1. Mandatory pooling of field operations, coupled with an adequate market price.
2. Education of the natural gas producers, and of the public, coupled with national constructive legislation. Any legislation, of course, to be of value to the public must be so framed as to stimulate production and the constant search for new supplies.

EFFECT OF GOVERNMENTAL OPPOSITION TO UNIFIED CONTROL.

The present governmental attitude in preventing unity of action in the gas field causes a decrease in the life of the leaseholds, stimulates waste, and increases the cost of the gas to the public. Gas field operating conditions should be regarded as a natural monopoly, so that in the development of the field one company, or one "operating pool," could space the wells properly, and drain the field only at the rate of its safe working capacity, thereby greatly increasing and strengthening the life of the field.

POOLING OF FIELD OPERATIONS MANDATORY IF WASTE IS TO BE REDUCED.

The economic fallacy of competition between untilities is now thoroughly established. Competition, either as a guarantor of good service or regulator of rates, has failed. The doctrine that the public is served best by a legalized and regulated monopoly has become a fixed part of American public utility jurisprudence, and ought to be applied to the mining operations in the natural gas field.

The maximum usefulness could be derived from a pool of oil or gas by its being controlled by one competent management, as under such conditions it could be developed with the least waste and at the smallest cost. However, rarely is a pool under one control; ordinarily a pool is divided among many owners. To get the best results the operators should act in unison for the protection of their common sources of supply and for their mutual benefit. To make cooperation among the producers in a field effective it seems necessary for them to organize with some central authority that can furnish protection against carelessness, inefficient, or even deliberately negligent acts of individuals. The center of this organization should be supplied with all the data affecting the common interests, which could be kept confidential if necessary, and from this information concerning conditions in the field general policies for development and operation could be outlined. That would work to the best interests of all concerned.

There is no business to-day in which, by its very nature, there is more need for cooperation than among the oil and gas operators, yet they have been able to do practically nothing by themselves. Nearly all attempts at cooperation among oil and gas producers have failed, primarily because there was no authority to compel the observance of the will of the majority by individuals who did not choose to follow the policies laid down.[1]

---

[1] Underground Wastes in Oil and Gas Fields and Methods of Prevention. Technical Paper 130, U. S. Bureau of Mines, pp. 4, 5, by W. F. McMurray and J. O. Lewis.

PROVINCIAL THINKING CAUSE OF MOST NATURAL GAS WASTE.

The provincial habit of looking at natural gas from the dwarfed viewpoint of local use and immediate present is the primary cause of our acute natural gas service problems of to-day. The history of the industry has been one of unrestrained waste and profligate disregard for the public's interest, inevitably increasing demands and obvious physical limitations of supply. This wanton waste has been emphasized by creating and then emphasizing provincial aspects rather than recognizing the true national and interstate nature of the business. The selfish motive of trying to keep the natural resources of a State within the State boundaries, so as to make consumers locate within the State boundaries in order to enable them to use the resource, has been the dominating feature.

The following are three typical economic provincialisms that have been attempted. Although all of these have been unsuccessful, nevertheless they have stimulated the idea that natural gas was so cheap as not to be worth saving, and have therefore been provocative of much waste and misuse:

1. Attempting to prevent exporting gas beyond State limits.
2. Attempting to restrict the pressure which might be maintained in main lines, with the manifest object of preventing sufficient pressure to accomplish satisfactory interstate transmission.
3. Special tax upon the production and transmission of natural gas, and generally this has sought to discriminate in the tax as between gas consumption inside the State as against that transmitted for consumption outside the State.

The urgent present need is a clear appreciation and willing recognition that in the equitable administration of natural resources, like natural gas, there can be no State lines, and that a capital "The" belongs in front of United States in our national name. There is no more sense or justice in any other State either preventing or directly or indirectly burdening the exporting of natural gas, than there would be in applying the same provincial idea to the transportation of food. If it would be just for any State to say that you can not use "our" natural gas unless you locate within our State boundaries, it would be just as fair for the Minnesota farmer to say you can not eat my wheat unless you live within the State boundaries of Minnesota, or for the Louisiana sugar planter to say you can not use my sugar unless you come and live within the State boundaries of Louisiana. The last two viewpoints are so ridiculous that they would not receive serious consideration; yet they represent precisely what has been specifically attempted in the distribution of natural gas.

CHARACTERISTICS OF NATURAL GAS PROSPECTORS AND NEW GAS SUPPLIES.

Natural gas prospectors are optimists, with individualism as the dominating characteristic. They are oversanguine, but if it were not for this characteristic they would not be searching for new supplies of gas. They do things in a big way, take large risks, are good sportsmen, and, therefore, good losers. However, the gains must in the end be more than the losses or they will not continue in the hunt for natural gas supplies for future service.

CONSERVATION OF NATURAL GAS POSSIBLE ONLY WITH PROFITABLE OPERATION.

Natural gas can be found only by diligent prospecting. After it is found the service can be maintained continuously only by further continued development and persistent searching for new supplies. In this development the prospector must figure on many dry holes. The average for all drilling in the entire United States is that every fourth hole is dry. In opening up new fields this may be much higher, brought out elsewhere.

Since the hazards are greater than in any other mining enterprise, the profits ought to be correspondingly greater. This element of profit is the only incentive which impels men to engage in so speculative an enterprise. If, in the aggregate, this amount of profit does not measure up to the hazards in the business the men will cease their work of prospecting and put their capital in safer enterprises. Wherever a close connection exists between effort and profit a stronger resulting incentive is furnished for a further and continuous expenditure of effort. Therefore, a high rate of profit, which will induce men to prospect continuously for natural gas, brings about the condition that more people can use gas and represents a distinct saving to the community.

Natural gas has never been equaled by any man-made product. The worth of natural gas for most high-grade utility services is ahead of any competing commodity or utility service. The only thing that will effectively conserve the supply for future use and thereby insure continuity of future service is an adequate price commensurate with the worth or value of the service. Therefore, the public is served best when natural gas mining is made profitable.

WHEN IS IT COMMERCIALLY FEASIBLE TO CONSERVE GAS OR DEVELOP NEW SUPPLIES?

The feasibility of conserving wastes or developing new supplies and connecting these with a market depends on the coordination of the following factors:

1. A study of the open-flow data in accordance with the doctrines laid down on page 20.

2. Number of dry holes that have been drilled.

3. Probable rock pressure decline.

4. New drilling necessary to maintain production.

5. Total investment necessary in "conservation project" to save the gas.

6. Total investment in leases, wells, compressing stations, and transmission lines necessary to connect the gas with a market.

7. Operating cost of all the preceding factors.

8. In no case would it be prudent business or good judgment to attempt to conserve a waste of gas or develop a new supply that would not take care of the fixed charges on the investment and the operating cost during the life of the gas that is saved or developed on the basis of the volume of gas that can be obtained from such an enterprise and manufactured through the ultimate consumer's meter at the present market prices. An adequate price is therefore the crux of the natural gas conservation question. Unless it is made worth saving by the public it will not be good business judgment to attempt to save it.

PUBLICATIONS OF THE DIVISION OF MINERAL TECHNOLOGY, UNITED STATES NATIONAL MUSEUM.

Publication 2421. Sources of nitrogen compounds in the United States, by Chester G. Gilbert. Issued June 30, 1916, Smithsonian Institution, 12 pp.

Bulletin 102, part 1. Coal products: An object lesson in resource administration, by Chester G. Gilbert. Issued Nov. 17, 1917. 16 pp., 11 pls.

Bulletin 102, part 2. Fertilizers: An interpretation of the situation in the United States, by Joseph E. Pogue. Issued Oct. 10, 1917. 22 pp., 1 pl.

Bulletin 102, part 3. Sulphur: An example of industrial independence, by Joseph E. Pogue. Issued Nov. 7, 1917. 10 pp., 1 fig., 3 pls.

Bulletin 102, part 4. Coal: The resource and its full utilization, by Chester G. Gilbert and Joseph E. Pogue. Issued Feb. 21, 1918. 26 pp.

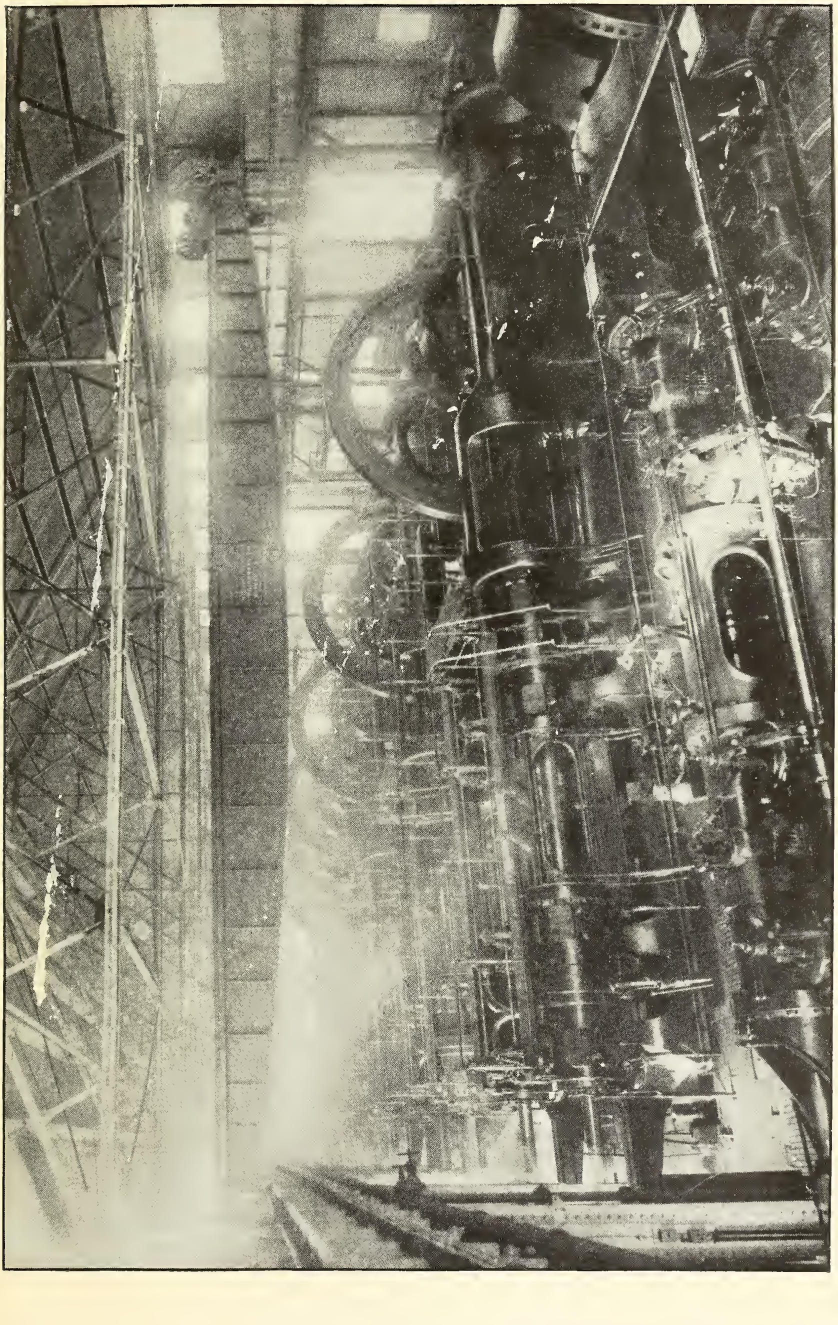
Bulletin 102, part 5. Power: Its significance and needs, by Chester G. Gilbert and Joseph E. Pogue. Issued Sept. 21, 1918. 50 pp., 2 figs.

Bulletin 102, part 6. Petroleum: A resource interpretation, by Chester G. Gilbert and Joseph E. Pogue. Issued Aug. 1, 1918. 76 pp., 12 figs., 3 pls.

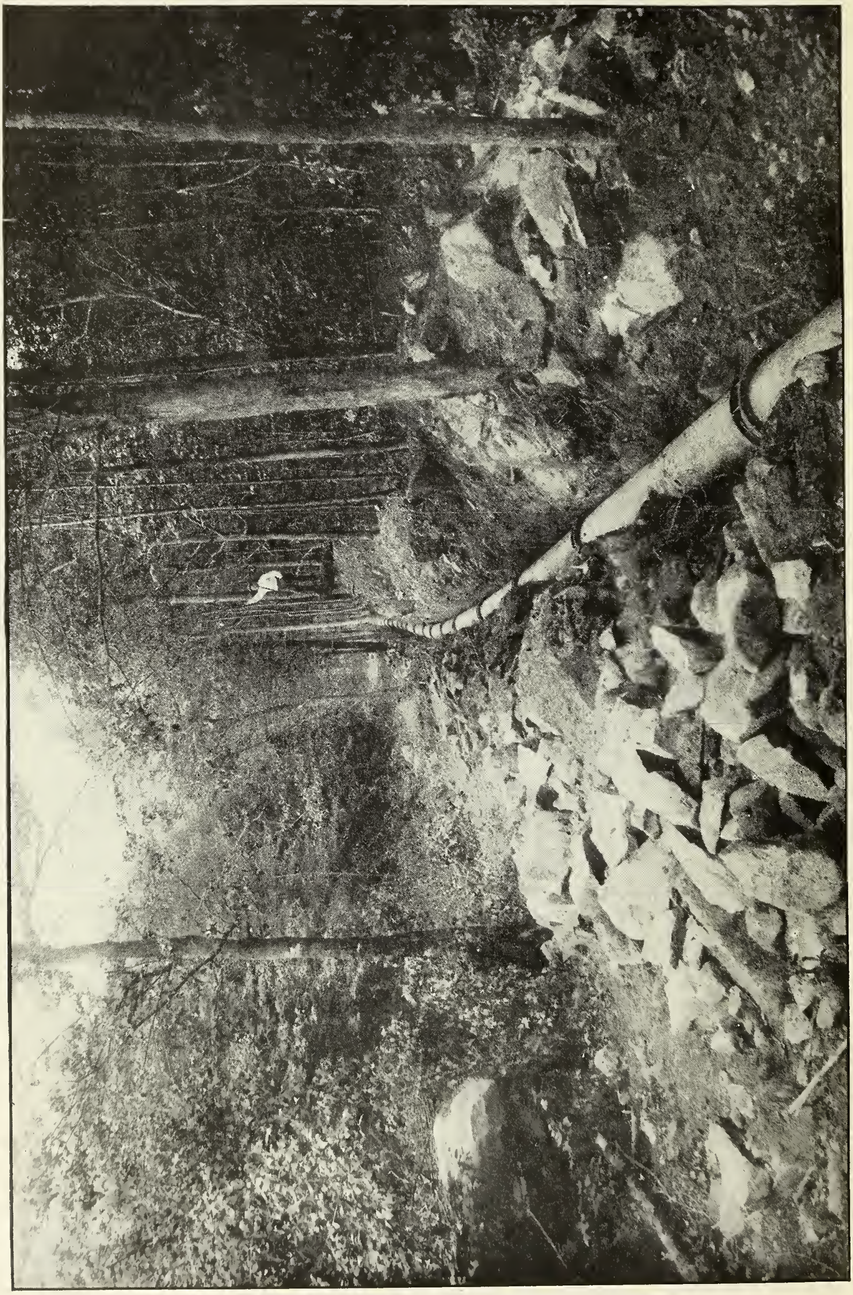
Bulletin 102, part 7. Natural gas: Its production, service, and conservation, by Samuel S. Wyer. Issued ———, 1918.

Bulletin 102, vol. 1. The energy resources of the United States: A plan for reconstruction, by Chester G. Gilbert and Joseph E. Pogue. (In press.)

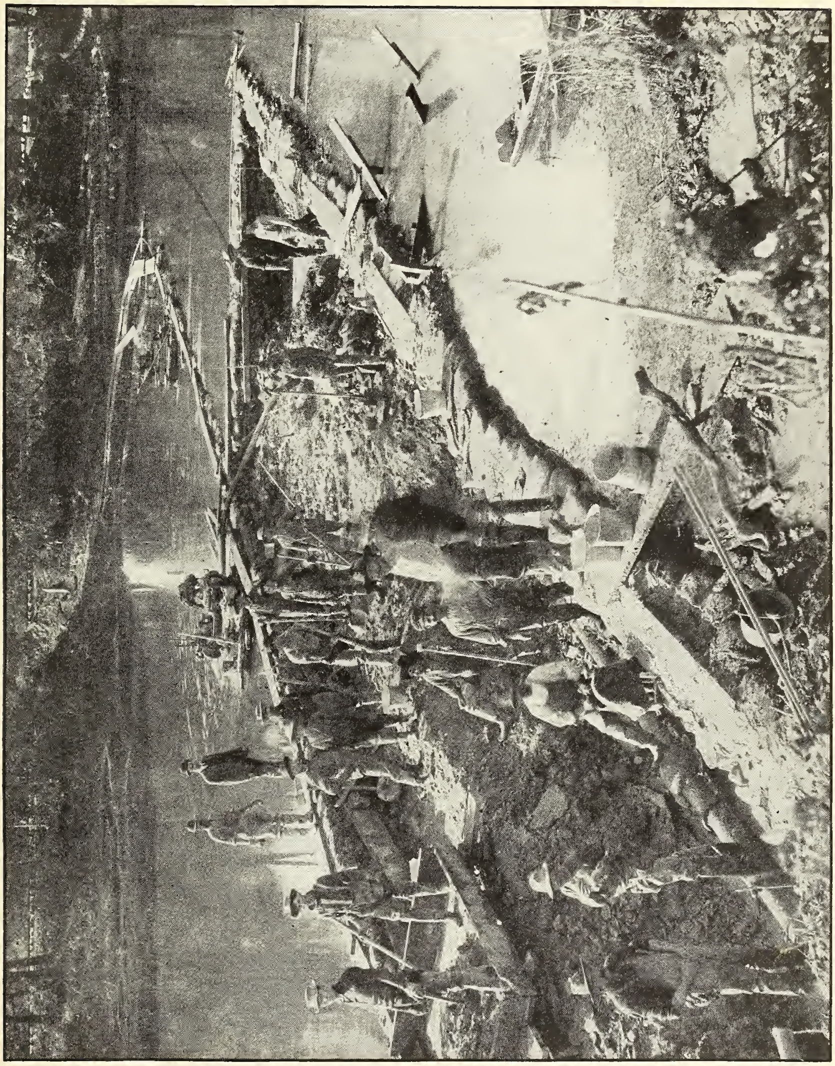
NOTE.—The papers listed above as parts of Bulletin 102 are members of a series entitled "The mineral industries of the United States."



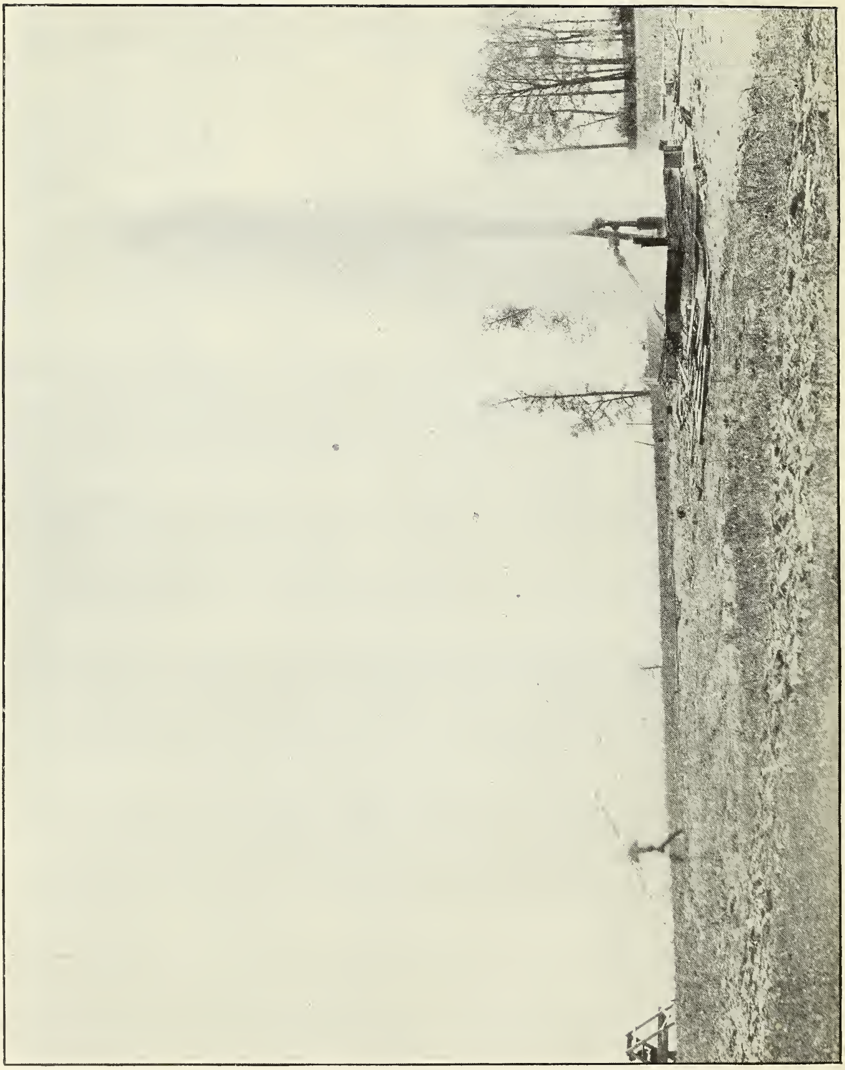
INTERIOR OF NATURAL GAS COMPRESSING STATION.



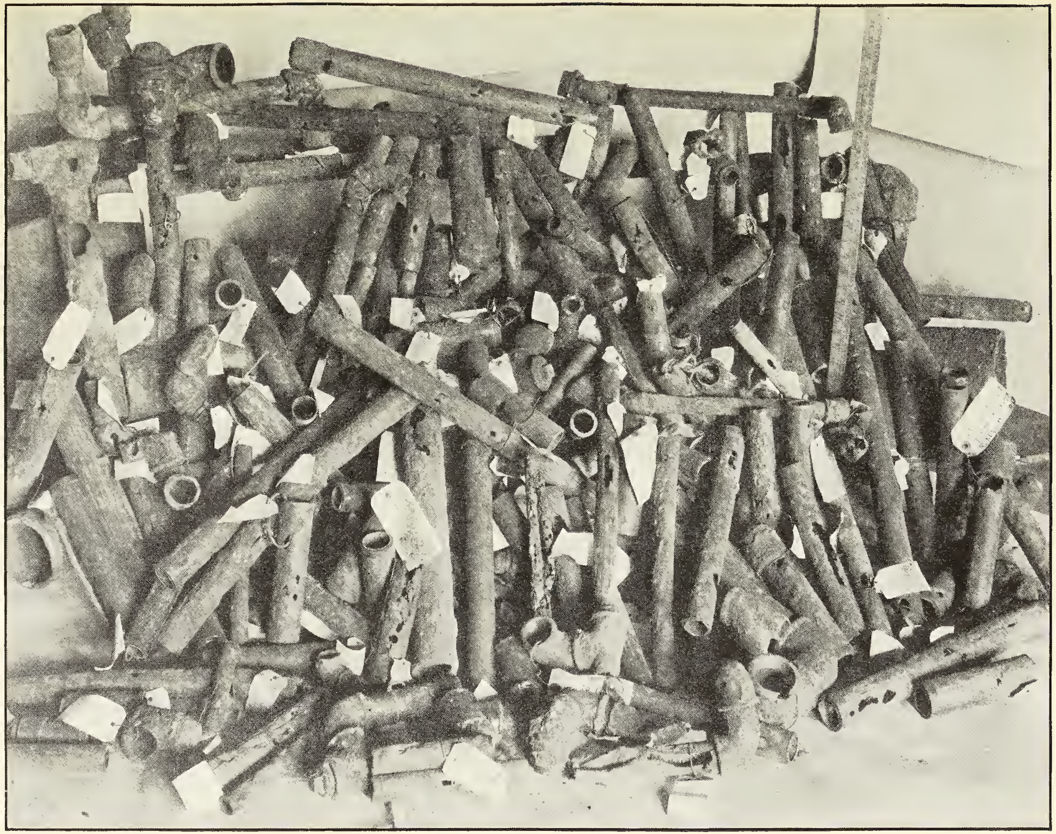
Natural Gas Main Line Construction Conditions.



Natural Gas Main Line River Crossing Under Construction.

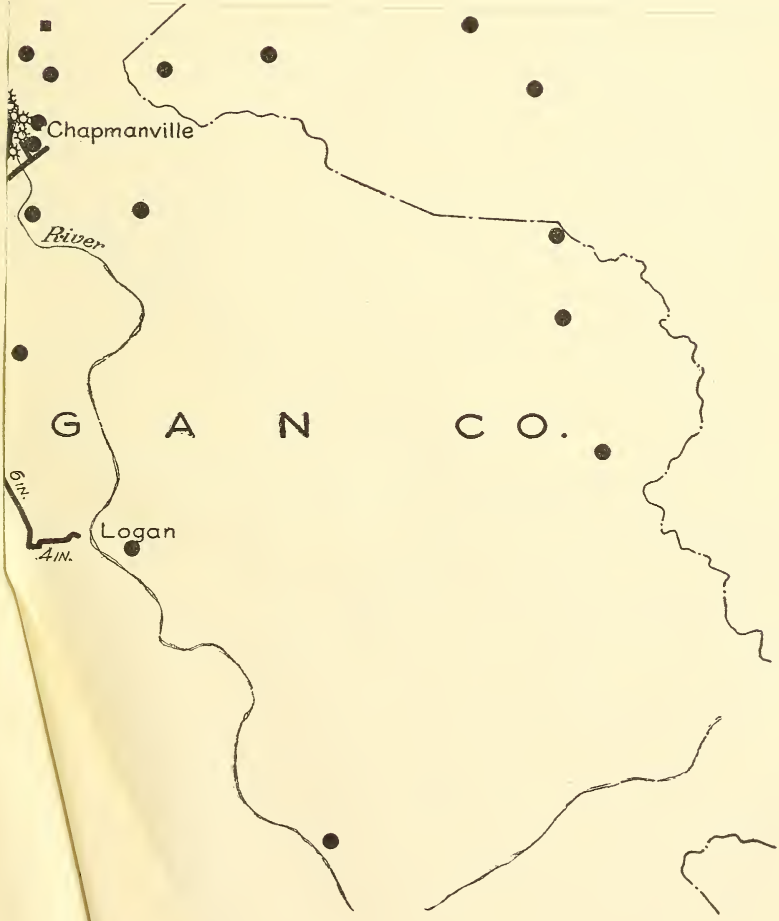


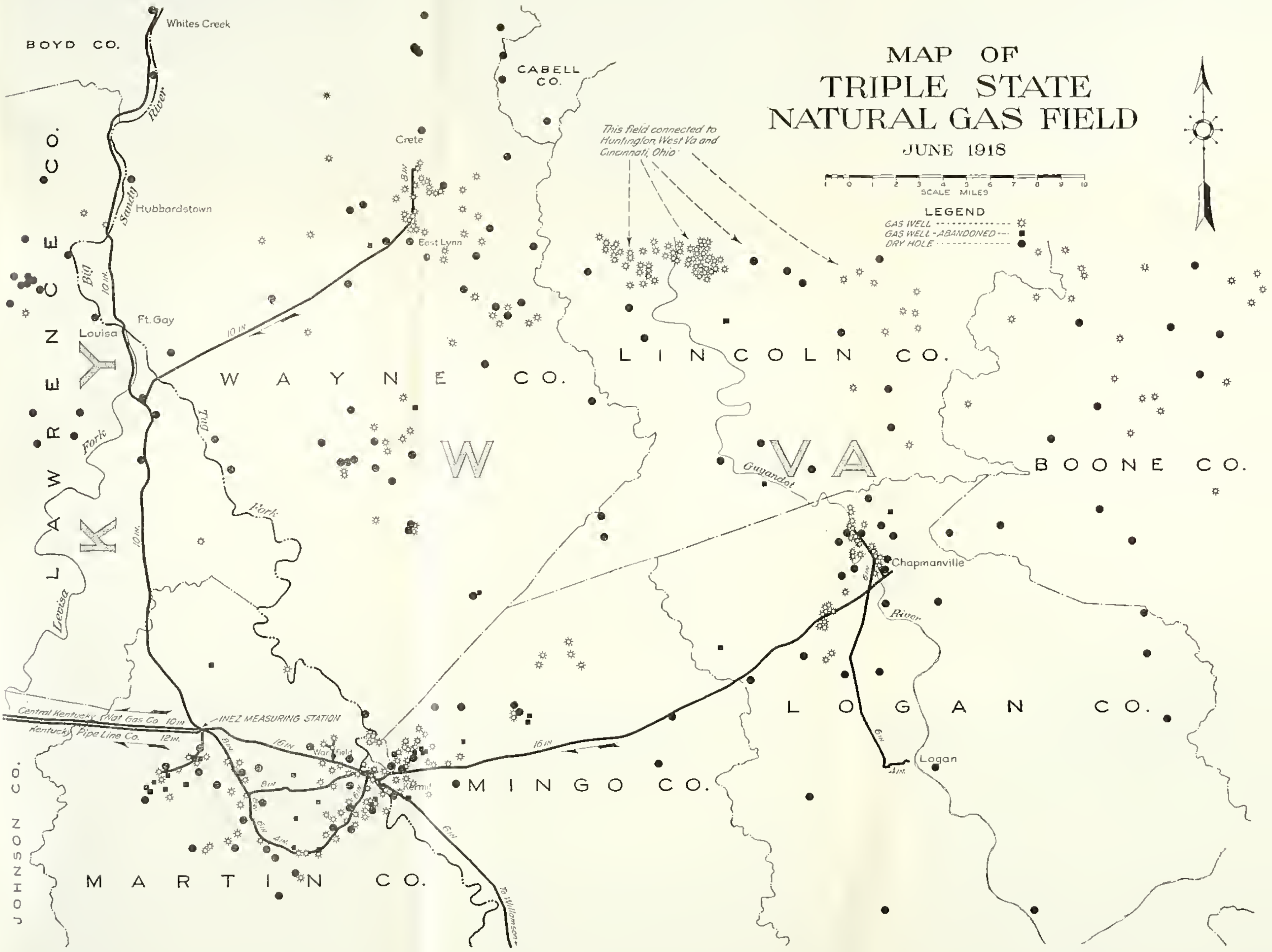
Waste of Natural Gas in Blowing Salt Water From Well.

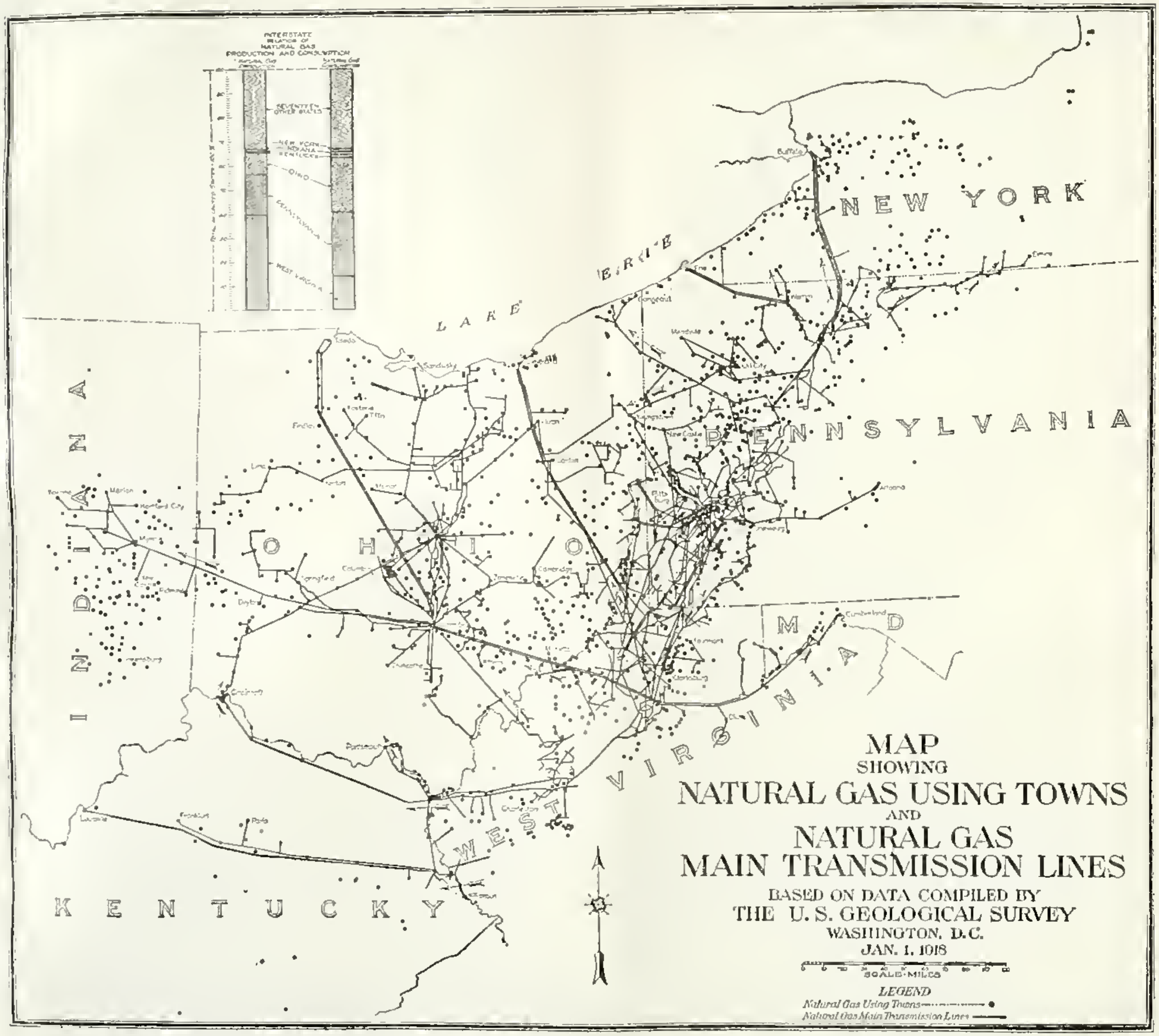


THE EFFECT OF ELECTROLYSIS ON GAS PIPE.

Gas pipe from Kansas City, Mo., showing holes produced by electrolysis, and therefore many opportunities for waste of gas through leakage. This also produces serious life and property hazard. The term "electrolysis" as here used means the destructive, disintegrating, chemical action, and the resulting damage of underground metallic structures when stray electric currents from electric railways have leaked from their own return circuit and wandered to other underground structures and thence back into the soil.


Chapmanville
River
G A N CO.
6IN.
4IN.
Logan


MAP OF
TRIPLE STATE
NATURAL GAS FIELD
JUNE 1918
0 1 2 3 4 5 6 7 8 9 10
SCALE MILES
LEGEND
GAS WELL ✲
GAS WELL - ABANDONED ■
DRY HOLE ●
This field connected to Huntington, West Va and Cincinnati, Ohio
BOYD CO.
CABELL CO.
LAWRENCE CO.
KY
JOHNSON CO.
MARTIN CO.
WAYNE CO.
LINCOLN CO.
W VA
BOONE CO.
LOGAN CO.
MINGO CO.
Whites Creek
Big Sandy River
Hubbardstown
Crete
East Lynn
Ft. Gay
Louisa
Levisa Fork
Tug Fork
Guyandot River
Chapmanville
Logan
Kermit
Warfield
INEZ MEASURING STATION
Central Kentucky Nat Gas Co 10 IN.
Kentucky Pipe Line Co. 12 IN.
To Williamson
10 IN.
8 IN.
16 IN.
6 IN.
4 IN.


INTERSTATE RELATION OF NATURAL GAS PRODUCTION AND CONSUMPTION
SEVENTEEN OTHER STATES
NEW YORK
INDIANA
KENTUCKY
OHIO
PENNSYLVANIA
WEST VIRGINIA
LAKE ERIE
NEW YORK
PENNSYLVANIA
OHIO
INDIANA
KENTUCKY
WEST VIRGINIA
MD
MAP SHOWING NATURAL GAS USING TOWNS AND NATURAL GAS MAIN TRANSMISSION LINES
BASED ON DATA COMPILED BY THE U. S. GEOLOGICAL SURVEY WASHINGTON, D.C. JAN. 1, 1918
SCALE-MILES
LEGEND
Natural Gas Using Towns
Natural Gas Main Transmission Lines

SMITHSONIAN INSTITUTION
UNITED STATES NATIONAL MUSEUM
Bulletin 102, Part 8

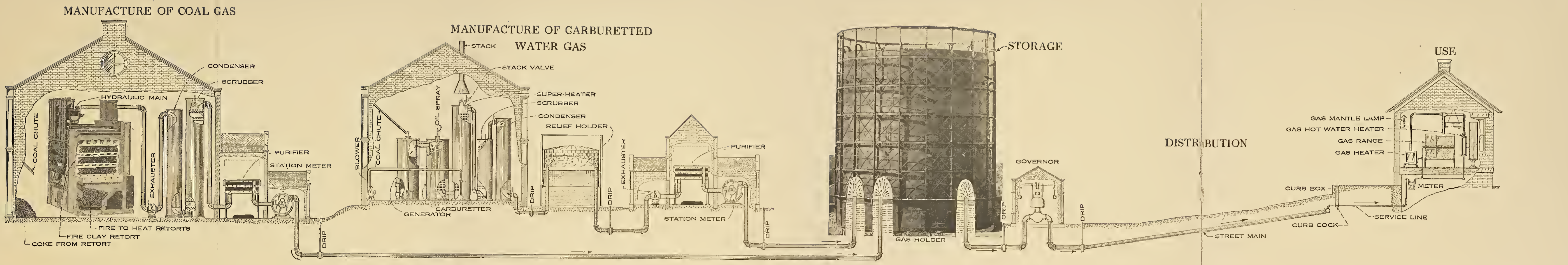
THE MINERAL INDUSTRIES OF THE UNITED STATES

MANUFACTURED GAS IN THE HOME

BY

SAMUEL S. WYER
Associate in Mineral Technology, United States National Museum

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923


MANUFACTURE OF COAL GAS
CONDENSER
SCRUBBER
HYDRAULIC MAIN
COAL CHUTE
EXHAUSTER
PURIFIER
STATION METER
FIRE TO HEAT RETORTS
FIRE CLAY RETORT
COKE FROM RETORT
DRIP
MANUFACTURE OF CARBURETTED WATER GAS
STACK
STACK VALVE
SUPER-HEATER
SCRUBBER
CONDENSER
RELIEF HOLDER
OIL SPRAY
BLOWER
COAL CHUTE
GENERATOR
CARBURETTER
DRIP
EXHAUSTER
DRIP
PURIFIER
STATION METER
DRIP
STORAGE
GAS HOLDER
DRIP
GOVERNOR
DRIP
DISTRIBUTION
STREET MAIN
CURB COCK
CURB BOX
SERVICE LINE
USE
GAS MANTLE LAMP
GAS HOT WATER HEATER
GAS RANGE
GAS HEATER
METER

MODEL SHOWING HOW COAL IS TRANSMUTED INTO GAS AND DELIVERED TO THE HOME

Condenser

This is fitted with tubes surrounded by water and arranged so gas goes through the tubes and the water absorbs the heat in the passing gas.

Scrubber

This consists of a cylindrical tower containing a number of wooden trays having slats running crosswise in checker board fashion and where a water spray at the top of the tower keeps the slats wet and washes the impurities down over the wet surfaces.

Purifier

This is a large box containing two trays of oxide of iron where the sulphur impurities in the gas are absorbed by the iron and removed from the gas. The top or lid of the purifier can be raised, as shown by the dotted lines above, for changing the oxide. A pile of oxide undergoing airing is shown on the floor underneath the purifier.

Gas Holder

This is merely an open top circular tank filled with water in which a smaller open bottom tank is placed so that the gas can fill the space between the water and the top of the smaller inside tank called a "lift." When the gas volume is increased, the lift rises, when the gas decreases, the lift descends. The weight of the lift produces pressure on the gas.

Station Meter

This is merely a large meter which measures the volume of gas manufactured as it goes to the storage holder.

Coal Gas

This is made by heating bituminous coal about 4 hours in extremely heated, air tight, retorts. Gas is driven off and a residue called "gas house coke" is left in each retort. This is withdrawn and a fresh charge of coal added. The gas evolved is withdrawn by the exhauster and pushed to the condenser where the tar and oil are precipitated and drained out at the bottom. The gas then goes to the scrubber where the ammonia is washed out and the resulting ammonia solution removed at the bottom. The gas now goes to the purifier where the sulphur is removed and then passes through the station meter and into the storage holder.

Water Gas

If water in the form of steam is brought into intimate contact with red hot carbon, hydrogen and carbon monoxide will be made. This is the basic feature of the water gas process. The steam will soon chill the carbon and the carbon must be heated again by shutting off the steam and blowing with air, making the process intermittent.

Carburetted[1]—That is, Oil Enriched—Water Gas

In order to increase the heating value of the blue gas and sometimes give it luminous qualities—although this is obsolete—oil under pressure is sprayed down over the hot brick work in the carburetter. The hot checker brick work in the carburetter and super-heater converts the oil into a fixed gas, this is known as carbureting and the gas is called "carburetted water gas."

The gas then enters the bottom of the scrubber by bubbling through a water seal which prevents the return flow of the gas. The scrubber washes the gas clean from its tar and carbon particles. The gas then goes to the condenser where the tar vapor carried is condensed and then drained out at the bottom. The gas then goes to the relief holder which equalizes the delivery beyond on account of the intermittent operation of the process. One complete cycle of getting the fuel bed ready and making a "run-of-gas" takes about 7 minutes.

The gas is pulled out of the relief holder by the exhauster, passes through the purifier which removes the sulphur and then through the station meter to the storage holder.

Storage

Gas is made at practically a uniform rate for 24 hours. The rate of use of the gas varies largely during different hours of the day. The function of the holder is to equalize the input and output.

Governor

As the gas comes into the holder and raises the telescoping sections, the weight of the metal that the gas must support increases and this increases the pressure on the gas, therefore, the higher the holder is raised the greater must be the resulting gas pressure.

To furnish a more uniform pressure to the consumer, the gas now goes through a governor which is merely a mechanical device where a variable intake pressure is changed to a practically uniform pressure in the distributing mains.

Delivery of Gas

From the governor the gas goes into the street mains, through the curb cock, service line, house meter and to the consumer's appliance.

Like the realization of an alchemist's dream, we have a serviceable transmutation of a baser substance into one of greater value in the unnoticed transmutation of crude, dirty, inert coal into energetic gas which can then be transmitted to a consumer far away where the turning of a gas cock makes it instantaneously available.

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[1] Official Spelling of the American Gas Association.

ORIGINAL IN
SMITHSONIAN INSTITUTION
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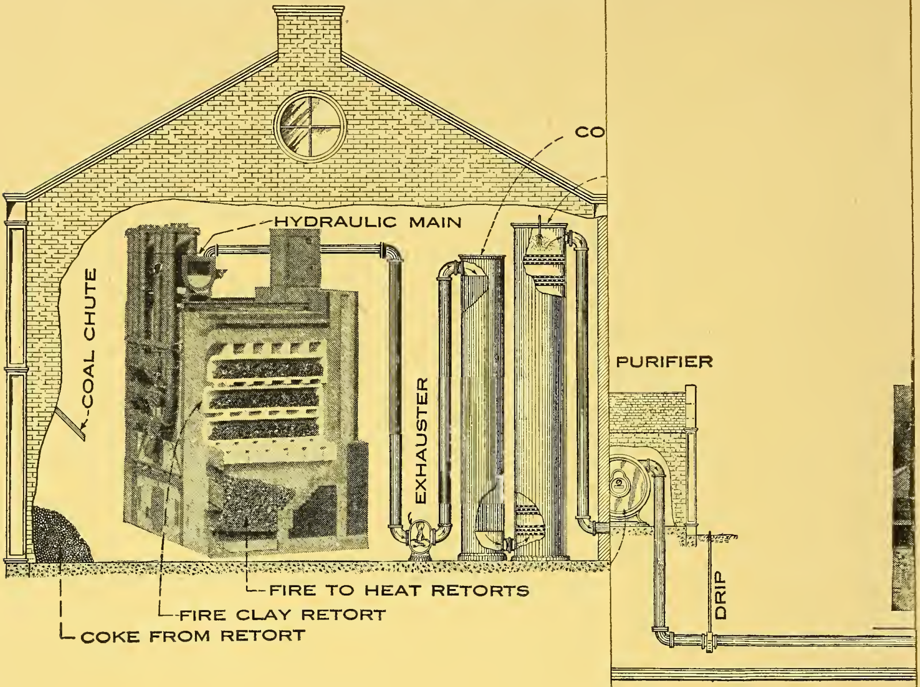
MANUFACTURE OF COAL C


CO
HYDRAULIC MAIN
COAL CHUTE
EXHAUSTER
PURIFIER
DRIP
FIRE TO HEAT RETORTS
FIRE CLAY RETORT
COKE FROM RETORT

Condenser

This is fitted with tubes surrounded by v goes through the tubes and the water absorbs t

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TABLE OF CONTENTS.

PART I. PUBLIC'S INTEREST IN MANUFACTURED GAS.

Page.
Magnitude 1
Growth 1
Geographical distribution 1
Effect of declining natural gas supply 1
Effect of home economics teaching 4
Gas small part of total meal cost 4
Relative cost of "home-cooked" and "ready-to-serve" cereals 5
Relative cost of various fuels 5
Electricity can not replace gas 6
How electric cooking and heating would waste coal 7
Waste of gas coals in beehive coke ovens 8
Governmental research on correct manufactured-gas use 8
Gas industry is rapidly changing 9
Volume of gas used not always increased by lower heating value 9
Classification of manufactured-gas consumers 10
How gas industry is related to smoke nuisance 10

PART II. CORRECT USE OF MANUFACTURED GAS.

Methods of utilization determine quality of service produced 11
Absence of gas-appliance regulations 11
What must happen when gas is burned 11
What may happen when gas is burned 12
Combustion products of gas can not be destroyed 12
Flueless heating stoves always dangerous 13
Flueless heating stoves more dangerous than flueless cook stoves 13
Blue-flame burners 13
Luminous-flame burners 14
Cooking requires little heat 15
Steps necessary for correct cooking 15
More gas is used for cooking in winter than in summer 16
Rusting of ovens and burners 16
Steps necessary for correct house heating 16
Steps necessary for correct hot-water heating 17
Lighting should be from incandescent mantle lamps only 17

PART III. ECONOMIC ASPECTS OF THE MANUFACTURED-GAS INDUSTRY.

Why economic aspects are controlling 19
What term "cost" must include 19
Definition of profit 19
Misleading manufactured-gas cost data 20
Significance of fixed charges 20
Characteristics of house heating 20
What peak load means 22
Analysis of house-heating problem 22
Variation in gas demand for house heating 23
Universal manufactured-gas house heating not feasible 23
Limitations of long-distance transmission of gas 23
Factors controlling by-product coke oven gas use 24

LIST OF ILLUSTRATIONS.

Page.
Model showing how coal is transmuted into gas and delivered to home ---- Frontispiece.
FIG. 1. Growth of manufactured-gas sales for public-utility service in the United States ---- 2
2. Number of manufactured-gas consumers in even thousands to each State ---- 3
3. Fuel small part of total meal cost ---- 5
4. Relative cost of "home-cooked" and "ready-to-serve" cereals ---- 6
5. Relative cost of various fuels for cooking a dinner ---- 6
6. Comparison of gas used by public and gas wasted in beehive coke ovens ---- 8
7. Classification of manufactured-gas consumers ---- 9
8. Action of gas mixer for Bunsen blue-flame burner ---- 14
9. Action of luminous-flame burner ---- 14
10. How fluctuations in atmospheric temperature varies demand for house heating ---- 21

MANUFACTURED GAS IN THE HOME.

By Samuel S. Wyer.

Associate in Mineral Technology, United States National Museum.

PART I.

PUBLIC'S INTEREST IN MANUFACTURED GAS.[1]

MAGNITUDE.

Manufactured gas is now used by more than 9 million domestic consumers in over 4,600 towns and serves about 46 million of our population. In 1921 over 326 billion cubic feet were sold to the public by gas companies in the United States.

GROWTH.

The earliest available United States Geological Survey data are for 1898. While the growth has been continuous since 1898, the annual growth has been especially rapid since 1915, as shown in Figure 1. The slowing down of growth, beginning about 1908, was due, in a large measure, to the then rapid increase in natural-gas use. The demands for hot-water and incidental heating in the home have been rapidly increasing, yet, at the present time, only about one-sixth of the domestic consumers have hot-water heaters and the hot-water heater growth in the future will be much larger.

GEOGRAPHICAL DISTRIBUTION.

The geographical distribution of manufactured-gas consumers by States is shown in Figure 2, where the figures indicate the number in even thousands of consumers in each State.

EFFECT OF DECLINING NATURAL-GAS SUPPLY.

The demand for natural gas is now greater than the available supply and less will be available each year. This now rapid decline will make necessary that the present natural-gas-using towns ultimately use manufactured gas if they are large enough to maintain a manufactured-gas plant. Many of the appliances now in use for natural gas are so crude and grossly inefficient that they can not be used at all with manufactured gas and this will make a marked demand for better manufactured-gas appliances.

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[1] The terms "artificial" and "illuminating" have been frequently used for this. Typical methods of manufacture and delivery to the home are shown on the folding plate at the front.

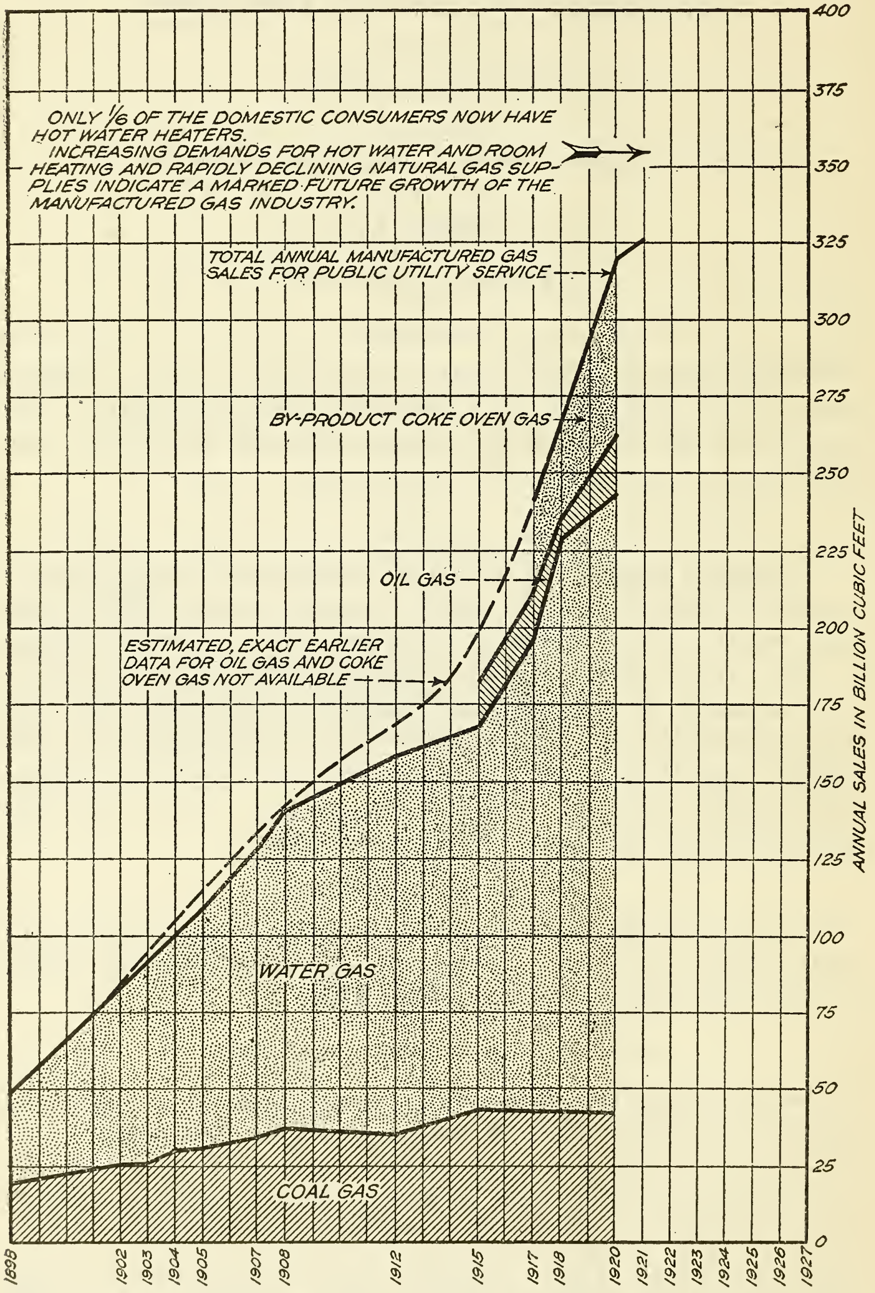

FIG. 1.—GROWTH OF MANUFACTURED-GAS SALES FOR PUBLIC-UTILITY SERVICE IN THE UNITED STATES.

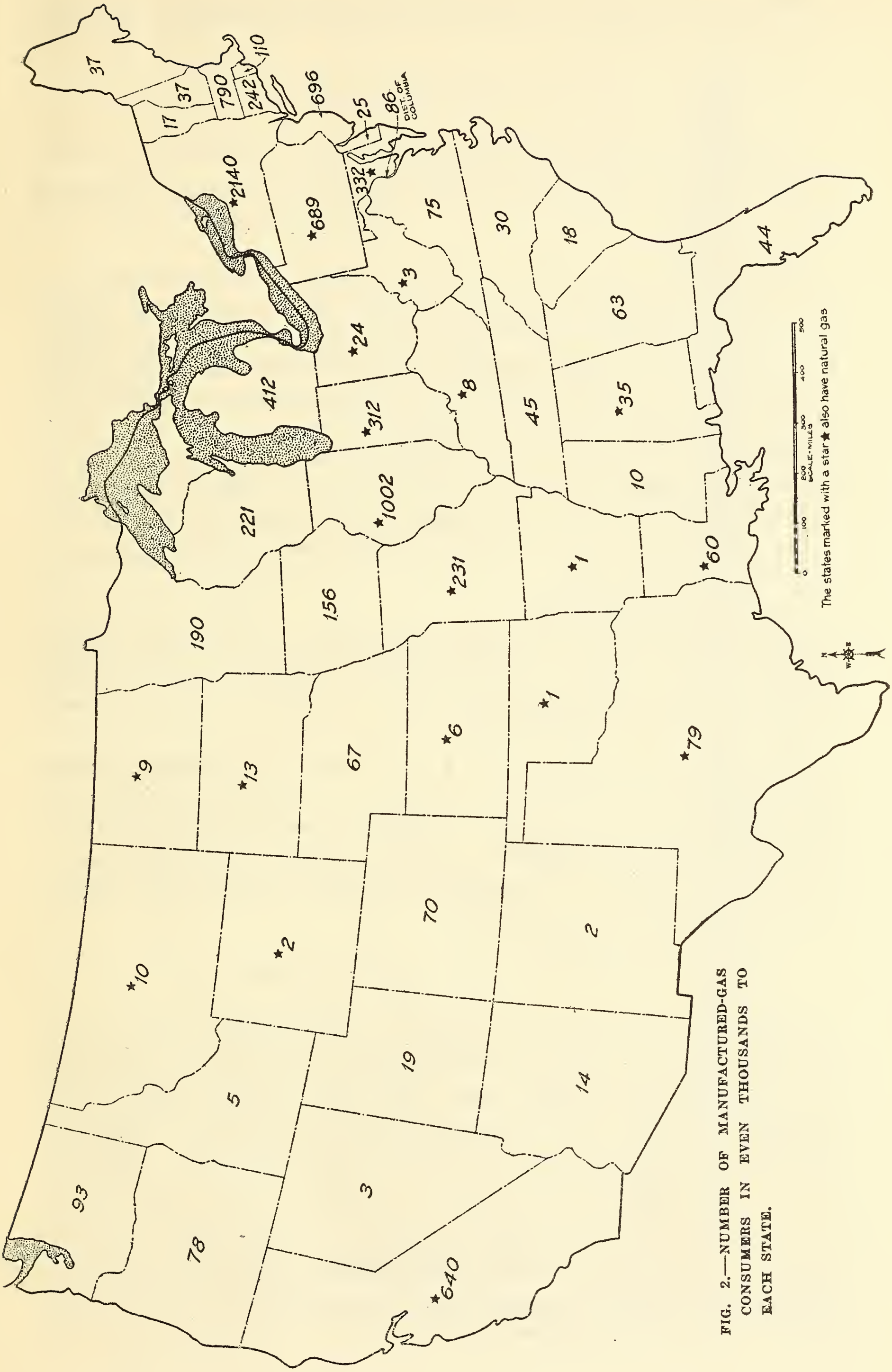
37
37
17
790
242
110
696
25
86
DIST. OF COLUMBIA
332
★2140
★689
75
30
18
44
★3
63
★24
412
★8
45
★35
★312
10
★1002
221
★60
★1
★231
156
190
★79
★1
★6
67
★13
★9
70
2
★2
★10
19
14
5
3
93
78
★640
0 100 200 300 400 500
SCALE - MILES
The states marked with a star ★ also have natural gas
N
W
E
S

FIG. 2.—NUMBER OF MANUFACTURED-GAS CONSUMERS IN EVEN THOUSANDS TO EACH STATE.

Referring to Figure 2, the States that have natural-gas consumers are shown by the stars.

EFFECT OF HOME ECONOMICS TEACHING.

In many towns more than one-half of the gas consumers are carried at a loss because they use so little gas that the cost of standing ready to render service and delivering the gas is more than the income received.

Most of this is due largely to our disintegrated home-life situation and habits of makeshift meals. Of the three essentials of family life—food, shelter, and clothing—food is the most important; therefore, the better and more economical preparation of the food is vital to the family. Since the life of our Nation depends on the preservation of our family life and, therefore, the stemming of the tide of indifference to and distaste of real home making and lack of appreciation that woman's greatest career is a home maker, anything that makes home meal service more attractive is worth while.

The teaching of home economics in the schools and elsewhere is growing at a rapid rate.

> In the United States at the present time there are 30,000 trained teachers of home economics teaching this subject in the schools; from 50,000 to 75,000 students of home economics in institutions of collegiate rank; and 800,000 to 900,000 pupils in the high schools and grammar grades taking either home economics or domestic science work.[2]

This must result in better living conditions, more bathing, greater use of hot water, increasing use of home-cooked foods, and the realization that the cost of gas for cooking is a small part of the total meal cost, as shown in Figure 3. These changes will result in an increasing use of gas for all domestic purposes, and the gas industry must meet this growing demand.

GAS SMALL PART OF TOTAL MEAL COST.[3]

The relative cost of the food and gas in preparing a dinner consisting of a thick or Swiss steak, escalloped potatoes, spinach, bread, butter, rice pudding, coffee, cream, and sugar, with portions for six people, as cooked on the ordinary gas range, is shown in Figure 3. The costs in cents are given opposite the respective items. The relative per cent, represented by each of the items, is shown by the 100 per cent diagram at the right-hand side. The food costs are based on current market prices, with manufactured gas at $1 for each thousand cubic feet.

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[2] Mary E. Sweeny, executive secretary, American Home Economics Association, Baltimore, Maryland.

[3] Based on tests made by Dr. Minna C. Denton, Office of Home Economics, U. S. Department of Agriculture, Washington, D. C.

A similar meal was cooked in an insulated oven where the gas cost was reduced to 2 cents.

RELATIVE COST OF "HOME-COOKED" AND "READY-TO-SERVE" CEREALS.[3]

This is shown in Figure 4, where the portions are for five people. The cereals are based on current market prices, with manufactured gas at $1 for each thousand cubic feet. The total costs for five people are shown in cents at the left. The cereal costs alone are shown by the black areas and the gas costs for the "home-cooked" cereals by the shaded areas. The cereals were cooked in the ordinary double boiler.

Another test was also made in which the cereals were cooked in a fireless cooker and with this the gas consumption was one-half of that shown in Figure 4.

RELATIVE COST OF VARIOUS FUELS.[4]

The relative cost of various fuels for cooking a dinner consisting of a thick or Swiss steak, escalloped potatoes, spinach, bread, butter, rice pudding, coffee, cream, and sugar, with portions for six people, is shown in Figure 5. The figures at the left indicate the fuel cost for each meal in cents at the respective unit prices of the various fuels.

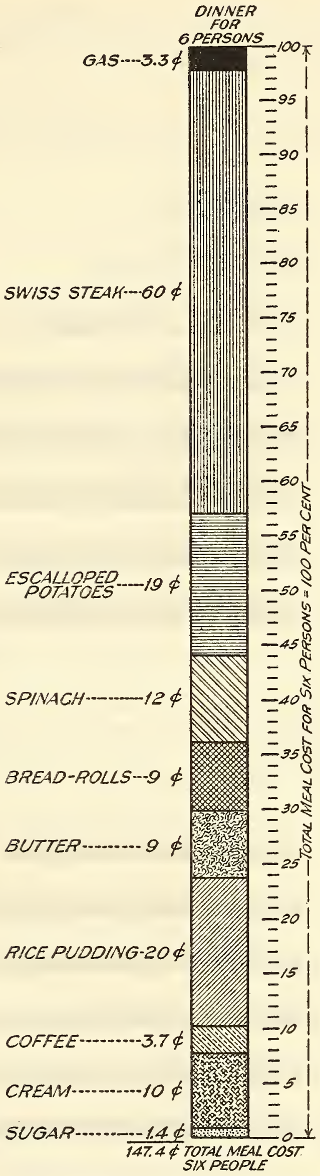

FIG. 3.—FUEL SMALL PART OF TOTAL MEAL COST.

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[3] Based on tests made by Dr. Minna C. Denton, Office of Home Economics, U. S. Department of Agriculture, Washington, D. C.

[4] Based on data from Office of Home Economics, U. S. Department of Agriculture, Washington, D. C., and department of home economics, Ohio State University, Columbus, Ohio.

ELECTRICITY CAN NOT REPLACE GAS.

There has been a temporary and unwarranted faith in the possibilities of electricity replacing manufactured gas for cooking and house heating.

People generally are hopeful and expectant when any theory is advanced or any suggestion made as to the possibilities of improvement or development of electric service. So many wonderful results have been attained by electrical experts in the past that the public mind is prepared for anything short of an actual miracle. When it is asserted that soon practically all the drudgery of labor will be eliminated by means of electrical appliances, and that heat will be released for our homes by simply turning an electric switch, with no dust or dirt, no laying in a supply of coal and no worrying over stoves and furnaces, there is a ready response in the public mind, accepted more readily, no doubt, because the wish is father to the thought.[1]

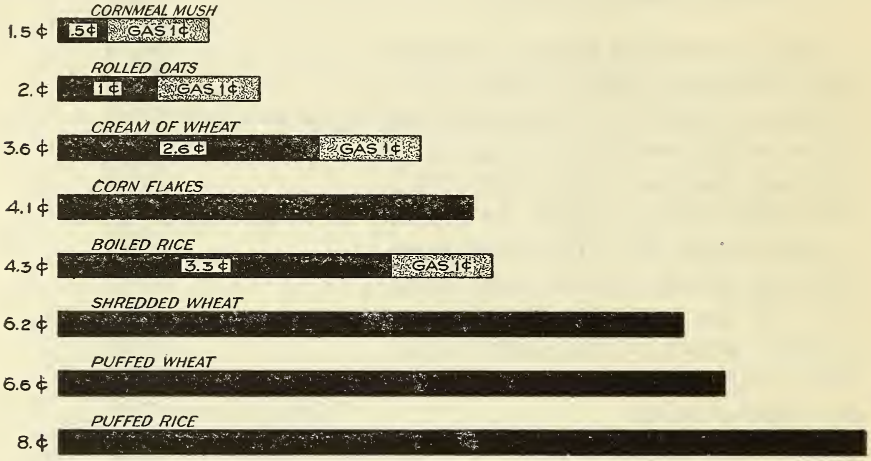

FIG. 4.—RELATIVE COST OF "HOME-COOKED" AND "READY-TO-SERVE" CEREALS.

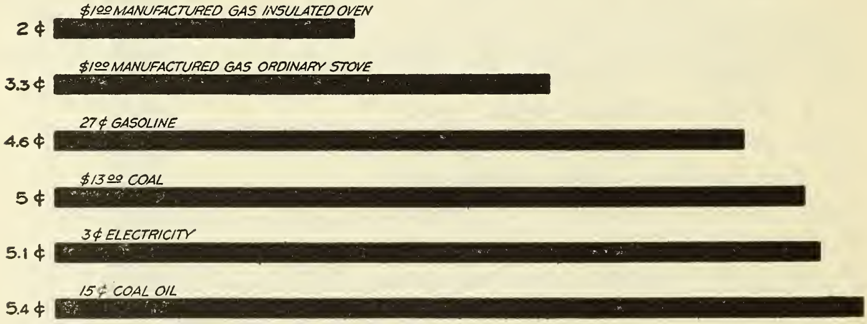

FIG. 5.—RELATIVE COST OF VARIOUS FUELS FOR COOKING A DINNER.

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[1] Public Utilities Commission of Idaho, Opinion on Electric Heating, Oct. 17, 1919, pp. 7 to 21.

A comprehensive study of the problem must make irresistible the conclusions that—

a. Electric cooking is a luxury for a limited few for whom reduced rates—except for quantity used—can not be justified in social justice and nondiscrimination to all consumers.

b. Electric heating of houses would be a gross waste rather than a conservation of fuel resources and so prohibitive in cost to users as to be beyond all consideration.

Therefore gas and not electricity must be depended upon for the cooking and house-heating service of the urban public for the future and the manufactured-gas industry must meet this increasing public-service obligation.

The possibilities of hydroelectric power are greatly overrated by the public generally. Hydroelectric power is not of itself, and under all conditions, even when the water power is widely available, more economical and cheaper than steam power. Water-power development can not, therefore, substantially change the electric cost situation.

HOW ELECTRIC COOKING AND HEATING WOULD WASTE COAL.[6]

A week's series of 21 meals, all of different menus, each for five people, were cooked with electricity. Exactly the same meals were then cooked with manufactured gas. The total weekly fuel consumptions for the 21 meals were as follows:[7]

Electricity	44 kw. h.
Manufactured gas (515 B. t. u.)	532 cu. ft.

	Pounds of coal.
Taking the average coal consumption—allowing for transmission losses and low load factor conditions at 4 pounds to the kilowatt hour as delivered at the consumer's appliance—the electric range requires 4 times 44	176
On the basis of complete gasification and 40,000 cubic feet of manufactured gas to the ton of coal, or 20 cubic feet of gas to the pound of coal, manufactured gas requires 532 divided by 20	27

Therefore about 6 pounds of coal would be required for electric cooking to 1 pound for manufactured-gas cooking.

The effect of the general use of electricity for cooking and heating on the Nation's fuel problem is shown in the following:

	Million tons of coal.
Total coal mined in the United States	640
Total coal required to generate electricity for cooking and heating service to 6 million homes in the United States	750
Total coal required to make manufactured gas for heating service to 6 million homes in the United States	82
Coal now used by all domestic consumers of coal in the United States	106

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[6] For further discussion see Salient Features of Electric Cooking, Electric Hot-Water Heating and Electric House Heating, by Samuel S. Wyer, Columbus, Ohio, 31 pp.

[7] Department of Home Economics, University of Washington, reported in the Journal of Home Economics, February, 1923, pp. 71 to 80.

WASTE OF GAS COALS IN BEEHIVE COKE OVENS.

At the present time, under average conditions, the beehive coke ovens in the United States waste annually about 240 billion cubic feet of gas, as shown in Figure 6, that could be used for public-utility service. Since the total annual manufactured gas sold is 326 billion cubic feet, as shown in Figure 6, this beehive coke oven waste is equivalent to nearly three-fourths of the gas sold. There is little wonder that the foreigner has referred to us as "butchers" in connection with the misuse of our own resources.

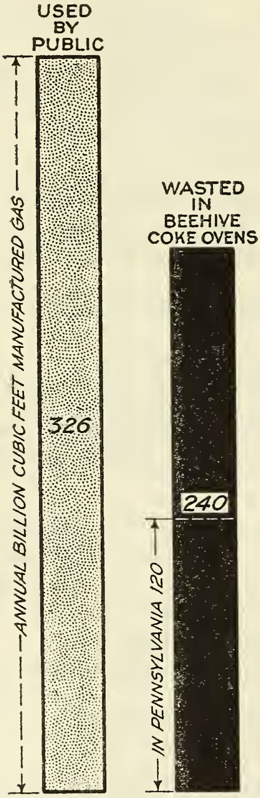

FIG. 6.—COMPARISON OF GAS USED BY PUBLIC AND GAS WASTED IN BEEHIVE COKE OVENS.

About one-half of this beehive coke oven waste, or 120 billion cubic feet annually, is wasted in the State of Pennsylvania. Since the manufactured gas used in the State is 27 billion cubic feet annually, this waste represents four and one-half times the manufactured gas made in the State.

Much oil is now needlessly used in maintaining obsolete candle-power standards.

GOVERNMENTAL RESEARCH ON CORRECT MANUFACTURED-GAS USE.

The United States Bureau of Standards has for several years been testing manufactured-gas appliances, ascertaining defects, and securing data for needed improvements.[8] The Office of Home Economics of the United States Department of Agriculture, in its experimental kitchen, has been carrying on extensive tests on actual cooking operations with gas under varying conditions of use. These tests have all brought out the many ways in which improvements may be made to bring about correct and safe use of manufactured gas. The results of these tests are reflected in the directions for correct use in part 2 of this bulletin.

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[8] For further discussion see Technologic Paper No. 193, entitled Design of Atmospheric Gas Burners, 62 pp., U. S. Bureau of Standards, Washington, D. C.

GAS INDUSTRY IS RAPIDLY CHANGING.[9]

Due to crude fuel and operating conditions, manufactured gas must rapidly go to a lower heating value standard. Only as the standards are lowered will it be possible to conserve the large amount of gas that is wasted in beehive coking operations and also curtail the large amount of oil that is now needlessly used in maintaining the candlepower or artificially high heating value standards.

Gas for lighting should be used only in incandescent mantle burners where the illumination comes from the heated mantle and not from any illumination properties of the gas. This is much more efficient and requires less gas than the old open-flame burner. A candlepower standard is, therefore, obsolete, of no value to the public, and should be abandoned.

VOLUME OF GAS USED NOT ALWAYS INCREASED BY LOWER HEATING VALUE.

The inevitable lowering of the heating value content of manufactured gas, made necessary by the changed operating conditions that must be faced, will not always increase domestic consumers' gas consumption. Generally much more gas is used than is needed for various cooking operations; that is, unless the food will actually burn, the gas cock is usually wide open. This explains why the lowering of the heating value of manufactured gas has frequently enabled the consumer to get the same satisfactory service without any increase in the monthly bill. With a 600 British thermal units gas the gas cock was kept wide open, and, for instance, when lowering to 500 British thermal units, the gas cock was still kept wide open and the consumer got all of the heat needed in the cooking operation, and was, therefore, satisfied because the ordinary measure of gas performance is the finished food in the usual time and not a specific number of heat units for a given operation.

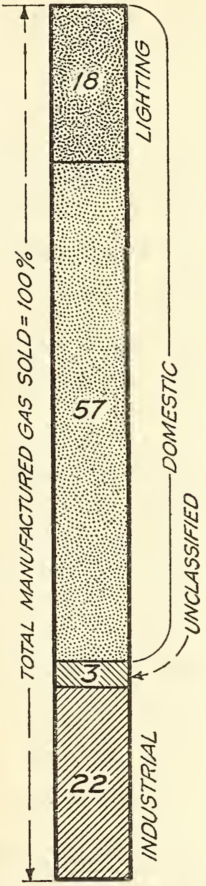

FIG. 7.—CLASSIFICATION OF MANUFACTURED-GAS CONSUMERS.

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[9] For further discussion see Technologic Paper No. 222, entitled Relative Usefulness of Gases of Different Heating Value and Adjustments of Burners for Changes in Heating Value and Specific Gravity, U. S. Bureau of Standards, Washington, D. C.

CLASSIFICATION OF MANUFACTURED-GAS CONSUMERS.

This is shown in graphical form in Figure 7, which shows that 75 per cent of the total gas sold is used for domestic purposes and only a small percentage of the total—namely, 18 per cent—for lighting, so that 57 per cent is used for cooking, hot-water heating, and other heating purposes.

HOW GAS INDUSTRY IS RELATED TO SMOKE NUISANCE.

> The verdict of hygiene in condemnation of coal smoke is: Of all enemies of national, racial, and social health I know of none which receives or ever has received so little attention in proportion to its importance.[10]

Smoke comes primarily from improper burning of bituminous coal. In most residential communities the trouble is largely from house chimneys. Smoke-prevention appliances—easily adapted to industrial plants—are not generally feasible in the home. Therefore smokeless fuels should be used.

The first step in the solution of the smoke problem is to educate the public to use gas correctly for cooking, hot-water heating, and incidental house-heating purposes and eliminate all soft coal use for cooking and hot-water heating purposes.

The second step is to educate the public to use coke [11] when anthracite is not available. Coke is merely the solid residue of bituminous coal after the volatile matter, which produces the smoke, has been removed; that is, it is a man-made anthracite. Saving this volatile matter in the form of by-product coke-oven gas and increasing the use of coke for house heating is necessary in order to eliminate the smoke nuisance. The proper use of gas and coke in the home will bring about the necessary public sentiment that must be crystallized in order to effectively control the industrial smoke problem.

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[10] For excellent discussion of hygienic aspects of the smoke nuisance see The Eugenic Prospect by Dr. C. W. Saleeby.

[11] Technical Paper 242, entitled Why and How Coke Should Be Used for Domestic Heating, U. S. Bureau of Mines, Washington, D. C., 17 pages of data giving operating details on how to use coke successfully for domestic heating.

PART II.

CORRECT USE [12] OF MANUFACTURED GAS.

METHODS OF UTILIZATION DETERMINE QUALITY OF SERVICE PRODUCED.

Gas service is radically different from every other kind of public-utility service in that the gas can not be used by the consumer as received, but—

First, must be mixed in proper proportion with another substance, atmospheric air.

Second, this mixture must then be completely burned.

Third, the flame must be so directed that the heat generated will effectively get into the food, air, water, or mantle that is being heated, with a minimum loss.

The results obtained will depend primarily on the gas-utilization appliance and the consumers' skill and care in operating. All these operating features are beyond the gas company's control, but are vital in determining the quality of the service produced by one consumer and the effect on the service of other consumers. Women, as a class, do not take easily to manual matters involving mechanical adjustments; so these facts, therefore, make obvious the need of education in the correct use of gas in the home. To meet this service situation, gas companies should give demonstrations and teach consumers correct and safe use of gas.

ABSENCE OF GAS-APPLIANCE REGULATIONS.

Much money and effort have been spent in developing and enforcing standards of gas quality. However, it has not been appreciated that the type of appliance and method of use are of much more consequence in determining the kind of service the consumer can get than the specific quality of gas delivered to the appliance.[13]

WHAT MUST HAPPEN WHEN GAS IS BURNED.

The combustion—that is, the burning of manufactured gas—can take place only by first mixing the gas with the proper proportion of atmospheric air. About 4½ cubic feet of air must be mixed, by the gas consumer at his burning appliances, with each cubic foot of manufactured gas in order to insure perfect combustion. If not enough air is mixed with the gas, the combustion will be imperfect and wasteful.

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[12] This discussion in part is similar to the original presentation in Technical Paper 257, U. S. Bureau of Mines, entitled Waste and Correct Use of Natural Gas in the Home.

[13] For further discussion see Technologic Paper No. 193, entitled Design of Atmospheric Gas Burners, U. S. Bureau of Standards, Washington, D. C.

When manufactured gas is burned by complete combustion, each cubic foot of the gas will form one-half cubic foot of carbon dioxide and 1 cubic foot of steam. This carbon dioxide is the same substance that is exhaled from the lungs.

The combustion of 1,000 cubic feet of manufactured gas will form 1,000 cubic feet of water vapor or steam, which when condensed, will make approximately 4½ gallons of water. It is this water vapor that causes the bakers and broilers of stoves to rust, and, when gas is used in open fires without flues, may make the walls and windows " sweat."

WHAT MAY HAPPEN WHEN GAS IS BURNED.

If the combustion of manufactured gas is not complete, carbon monoxide will be formed instead of carbon dioxide. This carbon monoxide is a deadly poison and, therefore, dangerous, and for this reason a room in which gas is burned should be ventilated. Although carbon monoxide itself is odorless, an offensive odor is usually produced by the improper combustion conditions that produce carbon monoxide. Therefore, an offensive odor from burning gas is an almost infallible indication of carbon monoxide generation. The poisonous action of carbon monoxide gas is so marked that one-tenth of 1 per cent is enough to in time produce fatal results. This poisonous gas is especially likely to be formed:

a. During first few minutes' operation of any automatic water heater.

b. When the inner cone of any blue flame impinges on a metal surface.

c. When a luminous flame is deflected and impinges on a cool surface.

d. When any flame is not supplied with sufficient air.

e. When a radiant fire heater is operated so that the radiants glow more than three-quarters of the distance from the bottom to the top.

COMBUSTION PRODUCTS OF GAS CAN NOT BE DESTROYED.

The inevitable products, carbon dioxide and water vapor, can not be destroyed, although the water vapor when it is cooled will condense to a liquid. There have been many claims made by manufacturers of heating devices that their devices absorb the combustion products, but all such claims are untruthful.

FLUELESS HEATING STOVES ALWAYS DANGEROUS.[14]

There are many so-called "odorless," "smoke-consuming," and "chimneyless" gas-heating appliances in use. These are always dangerous and a positive menace to health, and ought never to be used.

The gas industry should grow and meet the increasing future demands of incidental house heating. This desirable growth, however, may be retarded by untruthful claims that flues for room and water heating devices are not needed. Much depression and lassitude of spirit, lower vitality, and hence less resisting power to the ever-present disease germs may be traced to gas fumes from flueless gas-heating stoves. These vitiated room air conditions must be prevented if there is to be an increasing use of manufactured gas for heating service.

FLUELESS HEATING STOVES MORE DANGEROUS THAN FLUELESS COOK STOVES.

In the kitchen the cook stove is seldom used for more than one hour at a time. The volume of steam from the cooking food will be much greater than the volume of the combustion products from the gas, and the steam alone will make ventilation necessary.

The person in the room will be constantly moving about, with head 4 to 5 feet above the floor level, and in all probability the kitchen door will be opened several times during the cooking, thus increasing the ventilation.

In contrast with this condition, when a heating stove is used in a bedroom or bathroom, the period of use is much longer, the ventilation is less, the person in the room will be quiet with head closer to the floor, and the doors will probably, at least in the bedroom, not be opened or closed. Furthermore, a flueless stove properly adjusted at 9 o'clock in the evening, when the person goes to bed, may become a carbon-monoxide generator several hours later, due to deflection of the flame or small change in pressure, when the person is asleep.

Hoods over open-top kitchen stoves, of course, are always desirable.

BLUE-FLAME BURNERS.

Manufactured gas, to be burned in large volume, must have some of the air mixed with the gas before the gas reaches the flame. This is the fundamental principle of the Bunsen or blue-flame type of burner. The air taken in to form the mixture is called the primary air, and will usually be only a small part of the total air required. The rest of the air necessary for complete combustion, called the secondary air, will be taken from the atmosphere surrounding the burning flame. Such a blue flame does not smoke or deposit free carbon on a cool surface, although if the flame is sufficiently chilled some of the gas will escape unburned.

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[14] During the first 10 weeks of the winter in 1922 and 1923 there were 81 asphyxiations from flueless gas stoves in Ohio, of which 34 were fatal. All of these accidents would have been prevented by the use of proper flues. On Dec. 8, 1922, the Ohio State Department of Health issued a radio broadcast warning on this subject.

The action of the mixer is shown in Figure 8. The gas, at pressures above atmospheric air, is forced through a small hole by the pressure in the gas pipe, and thus acquires a relatively high velocity in passing through the small spud opening. In this way an aspirating or sucking action is produced around the orifice and this draws in atmospheric air from the room so it will mingle with the gas. A gas mixer is, therefore, in effect merely a small air injector. The amount of air going in may be varied by adjusting the air shutter.

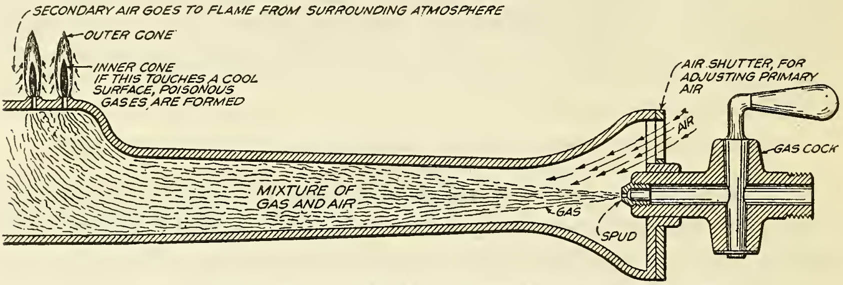
SECONDARY AIR GOES TO FLAME FROM SURROUNDING ATMOSPHERE
OUTER CONE
INNER CONE IF THIS TOUCHES A COOL SURFACE, POISONOUS GASES ARE FORMED
AIR SHUTTER, FOR ADJUSTING PRIMARY AIR
AIR
GAS COCK
MIXTURE OF GAS AND AIR
GAS
SPUD

FIG. 8.—ACTION OF GAS MIXER FOR BUNSEN BLUE-FLAME BURNER.

The mixer shown is of the type always used on cooking stoves, all hot-water heaters, all incandescent mantle lamps, room heaters of the radiant type, many other room heaters, and all house-heating furnaces or boilers.

LUMINOUS-FLAME BURNERS.

If manufactured gas is forced out through a small hole, about the diameter of a pin, enough air can be mixed with the issuing gas to insure perfect combustion. This is the principle of the yellow or luminous flame burner, as shown in Figure 9. The flames must not be permitted to come in contact with any solid body, because if they do they will deposit carbon and probably produce carbon monoxide. Only very small quantities of manufactured gas can be burned in such burners. In this yellow or luminous type of flame the production of the light is due to the incandescence of momentarily existing carbon particles furnished by the decomposition, by heat, of the gas itself, before coming in contact with the air.

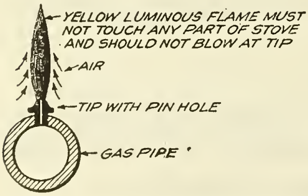
YELLOW LUMINOUS FLAME MUST NOT TOUCH ANY PART OF STOVE AND SHOULD NOT BLOW AT TIP
AIR
TIP WITH PIN HOLE
GAS PIPE

FIG. 9.—ACTION OF LUMINOUS-FLAME BURNER.

This burner never has a mixer for premixing part of the air as is required in the Bunsen blue-flame burner described in the preceding section. It can be used only for room-heating purposes and then only in positions where the flames do not impinge on each other or on any surface.

COOKING REQUIRES LITTLE HEAT.

That cooking operations require relatively low temperatures is not generally appreciated; that is, in all boiling operations the temperature is never above 212° F. and in all baking, roasting, and broiling operations it is always below 500° F.

The total amount of heat required to cook the food is very small and the heat that does useful work must not be merely delivered into the cooking vessel but must actually penetrate and get into the food. The big problem is, therefore, in directness and efficiency in getting the heat into the food and efficacy in insulation or holding it in.

STEPS NECESSARY FOR CORRECT COOKING.

a. The gas must be properly burned; that is, it must be properly mixed with air so as to burn with a pale blue nonluminous flame. A luminous flame will be wasteful and will deposit soot on the cooking vessel.

b. The flame must be properly directed; that is, the tip of the flame must come close to the cooking vessel. If the flame is too short to reach the cooking vessel, or is blown to one side by a strong draft of air, gas will be wasted, a longer time will be required, and if the flame tip is too far away it may be impossible to cook, although the short, improperly directed flames may be kept burning a long time.

c. In top-burner operations the heat generated by the burning gas must be delivered through the cooking-vessel walls and through the food. Grid or open-top stoves are desirable for good service so as to get the most direct path for the heat from the flame into the food. The heating of a baker is merely heating the inside of a small room and it should be fitted with a flue connection.

d. The use of insulated ovens so as to cut down the radiation losses will usually halve the gas consumption for a given gas operation as compared with the uninsulated oven. Thermostat control for gas consumption will result in better oven service, less gas consumption, and a saving in burned food; that is, it takes the "guess" out of cooking and insures duplication of results.

MORE GAS IS USED FOR COOKING IN WINTER THAN IN SUMMER.

The heating value of the gas in winter will not be any lower than in summer, because the heating value is increased 1 per cent for each 5° of decrease in temperature of the gas, and will actually be higher during the low temperature period in winter than it is in summer. However, the starting temperature of the food and water that must be heated in cooking will be much lower in winter than in summer; therefore, a larger quantity of heat will be needed to bring the food or water to the boiling point. The radiating loss from the cooking vessel and burner, because of the low temperature of the surrounding air, will also be much higher in winter than in summer, and thus will increase the gas consumption.

RUSTING OF OVENS AND BURNERS.

Rusting of ovens can almost be eliminated by opening the oven door slightly for a few minutes after the burners are lighted. This permits escape of the greater part of the moisture, which is produced by combustion, and prevents too rapid condensation.

Oven linings and burners are best protected from rust by the application of oil or grease, free from salt. This should be done while the oven or burner is warm, as often as may be necessary.

STEPS NECESSARY FOR CORRECT HOUSE HEATING.

a. The gas must be burned with perfect combustion. However, this is merely the first step.

b. The combustion products must be made to deliver the most of their heat into the air or water that is to be heated, and before leaving the heating device, and going into the flue, should be cooled to within 100° of the air or water that is heated. This requires adequate heat-radiating surface, a feature lacking in many appliances. Failure to appreciate the importance of this second step, rather than merely obtaining perfect combustion, is responsible for the gross waste of gas in so many heating devices.

c. The radiant-fire heater works on the same principle as the incandescent mantle lamp; the coarse or heavy radiant element replaces the fragile mantle. However, the radiant-fire heater should never be operated so the radiants glow more than three-quarters of the distance from the bottom to the top. When this rate is exceeded, carbon monoxide is liberated in more or less dangerous quantities.

d. With hot-air furnaces or steam or hot-water boilers, the use of a thermostat for controlling the gas will give more uniform and better temperature conditions in the living rooms and also save gas.

e. Flues should be fitted to prevent back drafts and smothering of flames.

STEPS NECESSARY FOR CORRECT HOT-WATER HEATING.

a. The gas must be burned in a Bunsen (blue-flame) burner with perfect combustion. Yellow flames must never be used. The inner cone of the Bunsen flame must not touch the metal surface of the water heater.

b. The heat produced by the burning of the gas must be transferred to the water in the most direct manner possible. The low efficiency of so many heaters is due to the inadequate heating surface so that the water does not have a chance to properly absorb the heat that has been produced.

c. The combustion products should be cool when they leave the heater and carried to a flue. The flue should be fitted to prevent back drafts and smothering of flame.

d. Automatic water heaters are of two classes:

(1) Instantaneous, where the flow of water starts the gas. These use gas for short periods at high rates of flow and may disturb the pressure conditions in the neighborhood.

(2) Storage with thermostat control. These use small rates of gas flow for longer periods but only to maintain a set water temperature in the tank.

e. If any form of storage is used, the heat delivered to the water should be held in; that is, the storage tank should be properly insulated to cut down the radiation losses. Insulation of hot-water pipes from heater to where they enter walls is also desirable.

f. With any form of storage tank the use of a thermostat for controlling the gas will result in better service and less gas consumption.

g. The heater or tank must be properly connected, cold water introduced at the bottom, and the hot water removed at the top. Provision should also be made for draining and blowing out of sediment.

LIGHTING SHOULD BE FROM INCANDESCENT MANTLE LAMPS ONLY.

The incandescent gas mantle lamp is simply a Bunsen burner where the burning gas heats the material in the mantle to incandescence, thereby producing light. The lamp must be closely adjusted if efficient and satisfactory results are to be obtained. Hissing or roaring sounds are indicative of excessive or bad adjustment. Adjust the lamp by adjusting the air shutter and gas needle valve of the burner—if the burner has one—so as to obtain a maximum illumination and a quietly burning lamp.

Open-flame burners should not be used because they require:

a. For a given amount of illumination about four times as much gas as an incandescent mantle lamp.

b. The maintaining of obsolete candlepower standards which can be of interest to only a very small percentage of the total number of consumers and squarely against the best service interests of the majority of the consumers. The gas used in open-flame illumination is so small as to be negligible in comparison with the total volume of sales which the consumers are generally interested in.[15]

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[15] For further discussion see Technologic Paper 110, entitled "The Influence of Quality of Gas and Other Factors Upon the Efficiency of Gas Mantle Lamps," U. S. Bureau of Standards, Washington, D. C.

PART III.

ECONOMIC ASPECTS OF THE MANUFACTURED-GAS INDUSTRY.

WHY ECONOMIC ASPECTS ARE CONTROLLING.

Economics is the philosophy of human industry; its function is to explain the " why " in man's efforts to supply his material needs. Every industrial activity must ultimately answer the question " Will or does it pay?" If it does not pay, it must eventually stop and the controlling factor is not engineering but the economic one of cost.

Economic selection is, therefore, based on a long-run cost. All permanent future manufactured-gas development—especially in the curtailing of waste—must reckon with this basic principle.

WHAT TERM " COST " MUST INCLUDE.

Regardless of the academic conception of the word " cost " and the wide variation in its use, as applied to any enterprise, the word " cost " in the inexorable law of human experience must always include the following:

a. Ordinary routine operating expenses necessary for carrying on the project including the various species of taxes and insurance.

b. Provision for the ultimate return to the owners of the value of the services or money put into the enterprise.

c. Rental or hire of the money used in the enterprise, ordinarily called " interest." There is no mysterious reservoir of capital and all money used for the carrying on of an enterprise must ultimately come directly from some individual owner and this owner rightfully has the obvious right to receive a hire or rental for the use of this, his property.[16] This rental of capital is a debt which must be paid before there can be a profit and like wages is an element of cost and not a part of profit.

DEFINITION OF PROFIT.

After the above three groups of expenditures have been fully met, then what is left represents profit, but there is no profit until the above three groups have been fully met. On this conception the cost of manufactured-gas development must stand or fall. This measures the difference between ultimate success or inevitable failure.

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[16] Large capital is steadily becoming more and more a mobilization of the savings of the small holder—the actual people themselves—and its administration becomes at once more sensitive to the moral opinions of the people in order to attract their support.—*Herbert Hoover in American Individualism.*

Merely providing for the three groups of expenditures in the preceding section will not yield any profit. Without a fair profit there is no incentive for improvement. Without improvement there can be no progress or development. Therefore an inducing profit is fundamentally necessary to continuously and permanently stimulate development of more efficient utilization methods of our fuel resources and extension of public-utility service.

MISLEADING MANUFACTURED-GAS COST DATA.

Many published data purporting to show the cost, especially the so-called *holder cost*—that is, the cost of gas delivered into the holder—or *burner cost*—that is, the cost of gas delivered at the consumers' burners—of manufactured gas includes only the element (*a*) of the above analysis. That is, provisions (*b*) and (*c*) were omitted with the result that many cost figures given are not correct.

SIGNIFICANCE OF FIXED CHARGES.

The rental for the use of the money, provision to ultimately pay the money invested, taxes, insurance, replacements, and repairs due to age or weather conditions, and some of the executive charges are fixed and go on for each of the 8,760 hours of the year and are entirely independent of the volume of the manufactured-gas enterprise's business. Of the total money paid by the public more than one-half must go to meet this fixed-charge situation.

Failure to appreciate the significance of this has been responsible for many manufactured-gas financial difficulties and inability to carry out fuel-conservation measures that were correct from a mere technical viewpoint but unsound from the viewpoint of economics. The economic and not the engineering features are, for this reason, ultimately controlling in all fuel-conservation projects.

CHARACTERISTICS OF HOUSE HEATING.

Wide variation in range of seasonal, daily, and hourly fuel needs are the dominating features of house heating. Atmospheric temperature will determine the consumer's needs and each degree drop in temperature will increase the consumer's demand for heating, as shown in Figure 10.

The consumer will not contract to take a specific amount of gas at a definite time but will expect to get all the gas he needs and to use it as he needs it. Manufactured-gas service for house heating must, therefore, cope with the varying demand, meet the peak-load

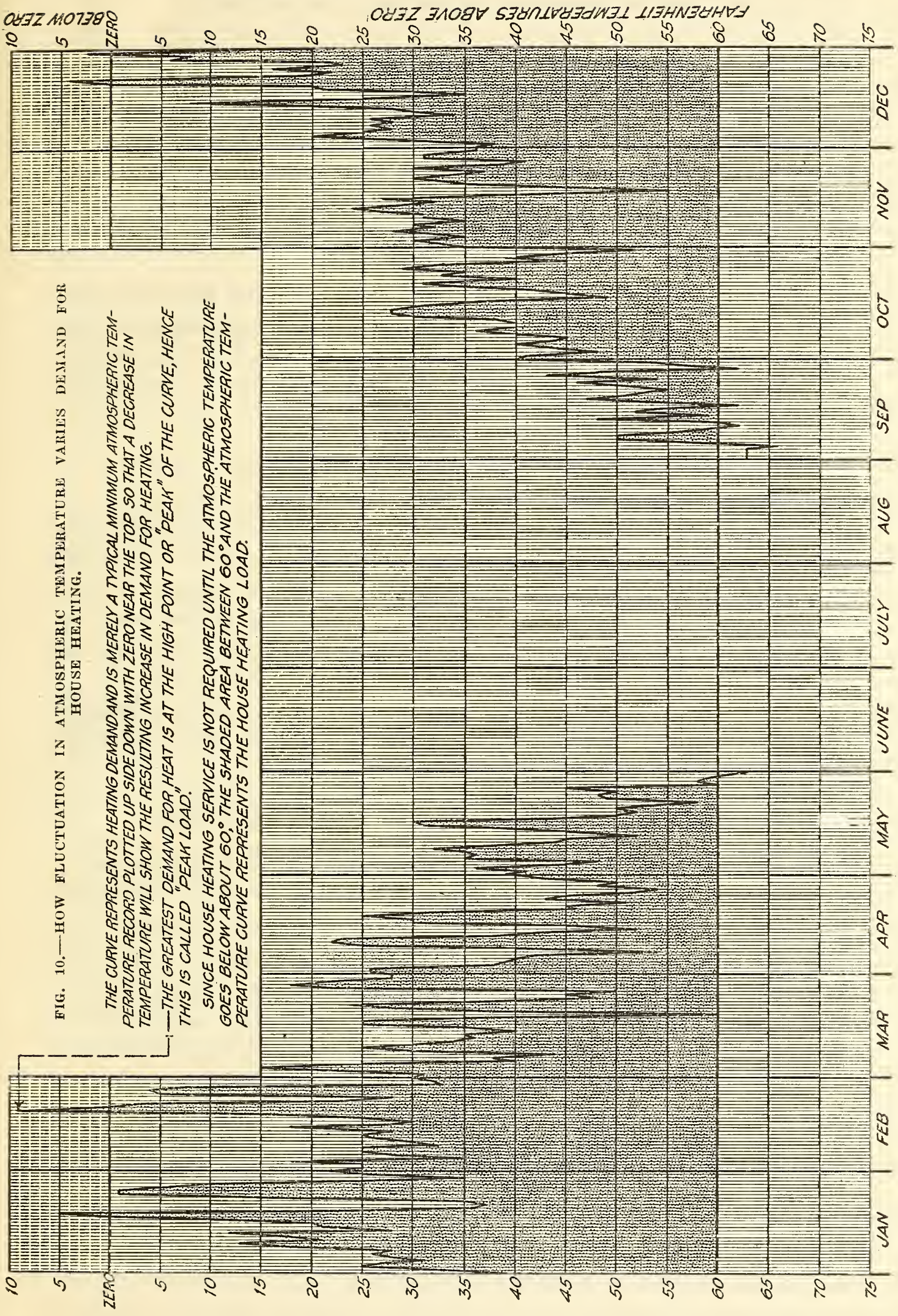

FIG. 10.—HOW FLUCTUATION IN ATMOSPHERIC TEMPERATURE VARIES DEMAND FOR HOUSE HEATING.

THE CURVE REPRESENTS HEATING DEMAND AND IS MERELY A TYPICAL MINIMUM ATMOSPHERIC TEMPERATURE RECORD PLOTTED UP SIDE DOWN WITH ZERO NEAR THE TOP SO THAT A DECREASE IN TEMPERATURE WILL SHOW THE RESULTING INCREASE IN DEMAND FOR HEATING.

—THE GREATEST DEMAND FOR HEAT IS AT THE HIGH POINT OR "PEAK" OF THE CURVE, HENCE THIS IS CALLED "PEAK LOAD".

SINCE HOUSE HEATING SERVICE IS NOT REQUIRED UNTIL THE ATMOSPHERIC TEMPERATURE GOES BELOW ABOUT 60° THE SHADED AREA BETWEEN 60° AND THE ATMOSPHERIC TEMPERATURE CURVE REPRESENTS THE HOUSE HEATING LOAD.

requirements, and yet use the capacity of the plant but a small part of the total time, as developed in the next two sections.

WHAT PEAK LOAD MEANS.

Plotting an atmospheric temperature curve, based on Weather Bureau records, upside down, so that a decline in temperature will go upwards, as shown in Figure 10, a graphical index of the consumer's capricious demand for heating service is obtained. The maximum demands are at the peaks of the curve and are, therefore, called peak loads.

Referring to Figure 10, note there are only nine peak demands where temperatures were 15° and only one where temperature was under 9°. The peak demand requires about one-third of the heating equipment and is used only about one and one-half per cent of the total 8,760 hours of the year.

ANALYSIS OF HOUSE-HEATING PROBLEM.

For a number of years an eight-room brick house, 29 feet by 34 feet—which would be an average size—has been heated exclusively with gas. The room-heating equipment is a hot-air furnace with 80 per cent efficiency; the water heater will run about 80 per cent efficiency. For room heating, water heating, cooking, and burning the garbage, this house requires:

	Heat units used.	Equivalent 1,000 cubic feet manufactured gas.
Peak-load demand an hour during extremely cold weather to keep the entire house warm	500, 000	1
Annual consumption	280, 000, 000	560

The annual plant capacity for the 8,760 hours in the year just to meet the maximum hourly demand equals 8,760 by "1,000 cubic feet" or 8,760 "1,000 cubic feet." The 560 "1,000 cubic feet" actually used, therefore, represents 6½ per cent of the total 8,760 "1,000 cubic feet" capacity needed to meet the peak demand. Therefore, the annual sales represent 6½ per cent of the total plant capacity that must be held in readiness to serve and meet the peak-load conditions.

The maximum hour peak of 1,000 cubic feet an hour does not occur every winter; in fact, has not occurred for two years. About 600 cubic feet an hour represents the maximum hourly demand of the usual winter, but when the extreme demand does come, if the gas service is unable to meet it, there will be an immediate complaint of the gas shortage and poor service.

VARIATION IN GAS DEMAND FOR HOUSE HEATING.

The average monthly variation in heat used for doing the room heating, water heating, cooking, and garbage burning for the house described in the preceding section, in terms of " 1,000 cubic feet " of manufactured gas, is as follows:

	1,000 cubic feet.		1,000 cubic feet.
January	130	August	6
February	110	September	6
March	80	October	24
April	50	November	50
May	22	December	66
June	10	Annual total	560
July	6		

The water heating, cooking, and garbage burning during the summer months average 6 " 1,000 cubic feet " per month. The maximum monthly gas consumption for house-heating purposes is, therefore, 130 less 6 equals 124 " 1,000 cubic feet." This shows that the maximum monthly heating load is more than 20 times the average summer load.

UNIVERSAL MANUFACTURED-GAS HOUSE HEATING NOT FEASIBLE.

The actual operating experience gained in the more than 2,000 natural-gas-using towns in complete house-heating service to a limited number of homes shows clearly the folly of attempting to render universal house heating in any town with manufactured gas because of the peak-load characteristics and the small percentage of the total time that the manufacturing and distributing plant equipment would be used.

Where house-heating service is to be developed with manufactured gas in any community on an extensive scale arrangements must be made for the individual consumer to carry the peak load with auxiliary fuels, like oil or coke, since it will not be economical to make the enormous investment in manufactured-gas-plant equipment in order to render this extreme service.

LIMITATIONS OF LONG-DISTANCE TRANSMISSION OF GAS.

The experience gained in transmitting natural gas through pipe lines indicates clearly the limitations that must be faced in attempting the distribution of manufactured gas from a central plant to a group of towns. No general statement can be made as to the dividing line between feasible distances and distances that will not be feasible since each case must depend on its own economic features. However, enough is known to show clearly that there has been an unwarranted faith in the possibilities of general manufactured-gas long-distance transmission and distribution.

FACTORS CONTROLLING BY-PRODUCT COKE-OVEN GAS USE.

The true significance of cost-factor, peak-load characteristics, and house-heating demands must be frankly faced with an appreciation that the economic and not the engineering features are controlling. To curtail the enormous waste of gas in beehive coke oven use, as shown in Figure 6, and secure an increasing use of by-product coke ovens, it will be necessary to reckon with the following:

a. Heating value standards for gas sold as a public-utility service must be lowered so as to create a market for and permit the general use of by-product coke-oven gas for public-utility service.[17]

b. The advantages of ammonium sulphate as a fertilizer must be stressed, soil conditions where it may be used studied and ascertained, and a market for this by-product created and maintained.[18]

c. Domestic consumers must be taught how to use coke for house-heating purposes.

d. Legislation against the improper burning of bituminous coal and the smoke nuisance must be enacted and enforced.[19]

e. In the lumber and grain industry, what is known as " milling-in-transit "[20] principle permits the shipment of raw material, then milling it at some favorable location en route, and reshipping the milled products at the original through freight rate. This " milling-in-transit " principle must be applied to the coke industry so that when coal is shipped the by-products may be removed while the coal is en route and the residue coke reshipped at the orginal through freight rate. This will permit the location of by-product coke ovens at the most advantageous locations for the immediate utilization of gas and other by-products for the reason that it will not be feasible from an economic viewpoint to transmit by-product coke-oven gas long distances through pipes.

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[17] For further discussion see Report of the Committee Appointed to Investigate and Recommend the Most Economic and Satisfactory Calorific Standard for Gas in Baltimore with Special Reference to the Available Supply of By-product Coke Oven Gas Mixed with Carburetted Water Gas, Public Service Commission of Maryland, Baltimore, Maryland, July, 1922, 182 pp.

[18] Smithsonian Institution, U. S. National Museum, Bulletin 102, part 2, Fertilizers: An Interpretation of the Situation in the United States, 22 pp.

[19] Smithsonian Institution, U. S. National Museum, Bulletin 102, part 1, Coal Products: An Object Lesson in Resource Administration, 16 pp.

[20] There are many reported cases discussing the " milling-in-transit " principle applied to lumber and grain industries in the reports of the Interstate Commerce Commission.

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